PERMIT COMPLIANCE HANDBOOK FOR WATER USE MONITORING AND REPORTING FLOW

South Florida Water Management District
West Palm Beach, FL

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INTRODUCTION

Water is a vital component in the history and survival of human and all other species. Over the years our attention has increasingly focused on the steady growth of industry and population and their demands on our fresh water supplies. Water supply issues can be contentious, centering on both quantity and appropriate quality for human consumption as well as environmental health. Exacerbating the issue further is that, in many cases, supply may be plentiful but seasonal distributions require careful planning for consumptive use, drainage and storage to ensure that adequate temporal distribution is achieved. Legislation has become increasingly stricter in response to our realization that fresh water, and even more importantly, potable water, is an extremely valuable commodity. In some areas of the country, fresh water is so valuable that water rights are not included in the acquisition of land and must be purchased separately. In other words, a person can buy land but has no legal right to surface or groundwater on, flowing through, or beneath that land parcel. In other areas, water supply is so overly abundant that adequate drainage is seen as the primary water supply issue. In South Florida, water availability is highly seasonal, creating the potential for both flood and drought conditions to occur in the same year, necessitating that equally intensive consideration be given to consumptive use, drainage, and storage. These extreme cases illustrate the complexity, uniqueness, and nonuniformity of issues related to the equitable spatial and temporal distribution of our fresh water supply.

To adequately provide supply, drainage protection and storage, water budgeting is essential. In order to develop a proper water budget, volume measurements are of the utmost importance. To obtain accurate assessments of available volume, flow measurements at points of flow into, and discharge out of, storage (both surface and groundwater) are absolutely essential. Accurate flow measurement data that enable continuous assessments of water supply are essential to responsible water budgeting. A regulatory program provides the vehicle by which uniform and reliable data are generated and interpreted in order to ensure sufficient water quantity at appropriate quality for all end users.

Over more than 30 years, the South Florida Water Management District has developed water use rules and criteria designed to preserve, protect and ensure an adequate supply of water resources within its jurisdiction. Specifically, Section 4.1 of the Basis of Review for Water Use Permit Applications within the South Florida Water Management District requires all permittees with a maximum monthly allocation of greater than three million gallons (greater than 15 million gallons in the South Dade County Water Use Basin) to monitor and report

withdrawal quantities from each withdrawal facility or point of diversion. The rule specifies that a reliable, repeatable water use accounting system must be identified to monitor water usage from all withdrawal facilities. The water use accounting method must be accurate to within +/-10 percent of the actual flow. Water use monitoring systems must be calibrated at five-year intervals or whenever significant structural/pump changes are made. Applicants must submit documentation of the water use accounting and calibration methods as part of the application for permit. Prior to the use of any withdrawal facility, the approved water use accounting system must be operating and the initial calibration submitted to the District by a qualified individual/entity. The rule applies to both gravity and pumped flow systems.

The District has started the cycle of irrigation basin renewals (Table 1), where all individual irrigation permits are evaluated, renewed and/or modified. This is being done on a staggered basis beginning in the Upper East Coast area in 2004 and concluding in the Kissimmee Basin in 2008. During this period, over 3,100 irrigation permits will be evaluated, renewed and/or modified. Virtually all of these permits were issued prior to the water use accounting and calibration requirements explained above. Hence, each current permittee must understand that these requirements must be met for permitted uses to continue.

Table 1: Permit Expiration Dates By Basin

Irrigation Permit Expiration Basin	Basin Application Date	Basin Expiration Date
Upper East Coast Basin A	October 30, 2003	February 28, 2004
Upper East Coast Basin B	February 28, 2004	June 30, 2004
Upper East Coast Basin C (excluding projects located within the Lake Okeechobee Basin)	June 30, 2004	October 30, 2004
Lower West Coast Basin A	October 30, 2004	February 28, 2005
Lower West Coast Basin B (excluding projects located within the Lake Okeechobee Basin)	February 28, 2005	June 30, 2005
Lower West Coast Basin C (excluding projects located within the Lake Okeechobee Basin)	June 30, 2005	October 30, 2005
Lower West Coast Basin D	October 30, 2005	February 28, 2006
Lower West Coast Basin E (excluding projects located within the Lake Okeechobee Basin)	February 28, 2006	June 30, 2006
Broward County Basin	June 30, 2006	October 30, 2006
Dade / Monroe Basin	October 30, 2006	February 28, 2007
Palm Beach County Basin	February 28, 2007	June 30, 2007
Lake Okeechobee Basin	June 30, 2007	October 30, 2007
Kissimmee Basin A (excluding projects located within the Lake Okeechobee Basin)	October 30, 2007	February 28, 2008
Kissimmee Basin B	February 28, 2008	June 30, 2008
Kissimmee Basin C	June 30, 2008	October 30, 2008

INTENT OF THE HANDBOOK

This handbook is intended to provide assistance to individuals/entities who fall under the jurisdiction of the Chapter 40E-2, F.A.C. Consumptive Use rules. These permittees are required to establish for each of their facilities one or more representative water use flow rates by using one of the calibrating methods discussed herein. Multiplying the flow rate by the time of operations will yield total volume used per event. On a quarterly basis, the permittees are required to report the volume of water used monthly by each of their facilities. The following chapters provide information about flow rate measurements and calculation, as well as information about operation time tracking and ways to report the volume of water used.

The document was prepared with the assistance of a variety of interested parties, including Agricultural Coalition of South Florida, professional engineers, consultants and others.

This handbook does not purport to be the definitive resource for flow measurement theory and methodology. Rather, it is written as a practical guide to identify common flow configurations, evaluating appropriate methods of flow monitoring for those configurations, selecting the appropriate instruments to use in measurement, assembling an acceptable monitoring program, and proper record keeping and submittal.

In Section A, some time is dedicated to basic hydraulics in order to give the user an understanding of the principles behind the flow measurement techniques and the ability to understand and identify anomalous configurations. Also, this section addresses the issue of inherent accuracy of instruments and methods, as well as calibrating systems to ensure acceptable accuracy levels on a continuing basis.

Section B contains training modules which will be used during the course workshops, as well as information regarding the District's calibration and water use accounting programs.

Section C represents an alphabetical listing and succinct description of several acceptable and practical flow measurements techniques. The description of each method is followed by an example of measurement information and calculation. Appendix A summarizes applicable choices for selecting flow verification (calibration) methods based upon the nature of the system to be measured. Appendix B contains the forms that are to be used to perform and fully document a flow verification (calibration); the forms are in alphabetical order by method. Appendix C contains useful conversions and measurements for length, area, and flow for pipes, canals, and ditches.

To add convenience to the process of designing, implementing and maintaining a monitoring system, Section D contains a listing and brief description of different types of flowmeters.

Finally, the guidebook is intended to be a resource that directs interested persons to vendors, calibration service providers, and additional resources (Sections E and F).

SECTION A

Basics Principles of Flow Monitoring and System Selection

SECTION A

BASIC PRINCIPLES OF FLOW MONITORING AND SYSTEM SELECION

BASIC HYDRAULICS

There are essentially two basic classes of flow systems: 1) closed conduits and 2) open channels. Flow in a closed conduit, however, may occur as either open channel flow or pipe flow. In the case of pipe flow, water fills the entire conduit and is not subject to atmospheric pressure, but rather hydraulic pressure. This type of flow system is best characterized by household water supply pipes, garden hoses, pipes and tubes in pressurized irrigation systems, and culverts installed so that they will always be submerged (below the lowest water surface expected). If the conduit is flowing only partially full, a free water surface occurs. The free water surface is defined as a water surface subject to atmospheric pressure. To best visualize this type of system, think of a culvert or sewer line flowing partially full. Water in these systems flows like a canal, but in a well-defined open channel, and is not acted upon by any imposed pressure other than that exerted by the column of air above it. In this case, open channel flow in a closed conduit exists.

Open channel flow must have a free water surface. In other words, the surface of the flowing water must be immediately in touch with atmospheric pressure. Atmospheric pressure is essentially the zero reference pressure that includes only the pressure applied by the vertical column of air above it. All canal flows, streams, rivers, ditches and partially full closed conduits fall into this category.

Regardless of the type of flow system, the discharge through a cross-sectional area of a channel or pipe, perpendicular to the direction of flow, is mathematically depicted as the conservation of mass equation

$$Q = V*A \tag{1}$$

where Q is the discharge in units of volume per time, V is the average flow velocity in units of distance per time and A is the cross-sectional area expressed as a distance squared. For the equation to be valid without conversions, the distance units used should be the same such that the solution is expressed as distance cubed (volume) per time (i.e. ft/sec*ft^2 = ft^3/sec). This equation serves as the basis for any flow measuring method or device.

Applying the conservation of mass equation (1) to pipe flow in closed conduits to determine discharge over time is relatively simple. The cross-sectional area of flow is easy to determine since the pipe has a rigid and unchanging shape and is, by definition, flowing full. Determining average flow velocity can also be fairly simple, using a variety of techniques. For open channels, both measurements become more complicated as accurately assessing the cross-sectional area of flow is often dependent on being able to measure as much of the nonuniformities of the channel bottom and sides as possible. Generally, simplifying and accuracy reducing assumptions are made to attain an approximate channel shape, including assuming smooth bottoms and sides or using the trapezoidal rule to account for gross nonuniformities by breaking the cross-section into narrow columns. Average velocity measurements are also more complex because of the lack of a well-defined flow boundary and the characteristic free water surface. For flow in partially full pipes, the cross-sectional area of flow is well-defined. However, that area of flow for any situation other than full or half full conditions requires the use of a complicated mathematical formula for finding the area of a segment of a circle (www.mathforum.org/dr.math/faq/formulas/faq.circle.html; www.1728.com/circsect.htm; Standard Mathematical Tables, CRC Press).

A common equation used to calculate flow in open channels is the Manning Formula written as

$$Q = \frac{1.49*A*R^{2/3}*S^{1/2}}{n} \qquad (2)$$

where Q is flow in ft^3/sec, A is the cross-sectional area of flow in ft^2, R is the hydraulic radius in ft (cross-sectional area of flow divided by the wetted perimeter), S is the slope of the hydraulic gradient (slope of the water surface between two points), and n is Manning's roughness coefficient (available in numerous publications in table form). This formula is best used when dealing with a long, well defined and uniform channel (smooth concrete culvert flowing partially full) and loses accuracy as the channel bottom becomes less uniform and more and more rocks, weeds, and channel bottom irregularities makes the selection of "n" no more than an educated guess. As can be seen comparing Equations 1 and 2, the Manning Formula is an attempt to approximate the flow velocity term using the energy slope, flow geometry, and a "resistance to flow" parameter, n. Its roots in the basic conservation of mass equation are more than evident.

For the record, there are other equations that attempt to improve on the Manning Formula, but further discussion of this type would over-complicate the matter at hand. Suffice it to say that while directly applying the conservation of mass equation, one would need to accurately measure values of the mean velocity and cross-sectional area. Using the Manning Formula, a more complete characterization of the channel bottom would be necessary to calculate R, an "n" value would have to be selected, and ongoing field measurements of the water surface elevations would have to be taken. With the development of direct velocity measuring instruments and more sophisticated flow calibration instruments, relying on the Manning formula would have little value in a program such as this one. However, it is one of the equations that characterizes the theory behind direct flow measurement.

The final nonspecific hydraulic equation that begs mention in any hydraulic primer is the Bernoulli Equation written as

$$H = z + d + v^2/2g \tag{3}$$

where H is the total energy at the channel section, z is the vertical distance of the section bottom from a datum representing zero energy due to depth, d is the vertical depth of water at the section measured from the channel bottom (representing pressure and in closed conduits applications written as P), v is the flow velocity and g is the acceleration of gravity (32.2 ft/sec^2). The equation simply states that the total energy at the channel section is the sum of the energy due to height relative to a datum, the energy due to the depth/pressure of the column of water, and the energy due to flow velocity. The equation is mentioned here since conservation of energy principles are used in the derivation of other flow equations and in the design of some types of meters (e.g. Venturi meters, flumes, etc.).

UNDERSTANDING FLOW MEASUREMENT ACCURACY/ERRORS

First, let's define error and accuracy. They represent the same thing, but present it from a different perspective. They are both depictions of how close a measured value of flow is to the actual or true flow. Error is defined as the amount by which you missed the true value, where as accuracy is defined as how close to the true value the measurement is. For example, if the measured flow was 105 cfs and the true flow was 100 cfs, then your error would be 5% (105 minus 100 divided by 100 then converted to %), while your accuracy would be 95% (100% - error as a %). A flow measurement is typical described as having an accuracy of ± the error.

The determination of accuracy/error of a flow measurement technique is predicated on being able to know the actual or true flow. This is typically done by the use of a secondary measurement technique of a known accuracy. For example, if an inline flowmeter is being evaluated for accuracy, then a second flow measurement device with known measurement accuracy will be temporarily used to measure flow just up or downstream of the flowmeter being

tested. The flows of the two devices are then compared to determine accuracy. The estimated error of the tested flowmeter will be the difference between the two measurements divided by the flow measured by the second device plus its known error, mathematically expressed as

Error = (Tested Device's Flow – Second Device's Flow)/Second Device's Flow
+ Error of Secondary Device

All flow measuring devices are shipped with stated error or accuracy specifications. Error may be stated as percent CS or percent FS. Percent CS refers to the accuracy over a calibrated span. Percent FS refers to accuracy over the full scale of the device. Hence, reported %FS error will

always be higher than reported %CS. The third statement of error is specified as a percent of the actual reading, or %AR. Percent AR error (error in absolute terms) will not change between high and low flows. To ensure that error calculations and statements are sufficient and comparable, all error estimations should be converted to %AR. Further, errors occur in other aspects of the flow monitoring routine. For example, in streamgaging, a typical magnetic flowmeter will have and error associated with it. In addition, there are errors associated with the instrument used to measure the depths of water across sections of the canal. The total inaccuracy of the instruments used must be calculated by summing the squares of the two errors and taking the square root of the resulting sum. Other errors will also be introduced in estimating channel cross-sectional area, by leaky structures, seepage into or out of the channel, turbulence, wave action, floating particles, aquatic flora and fauna, improper recording, etc. Essentially, any number of things could cause errors in measurements. The errors are sometimes simply unavoidable. Hence, a person should simply ensure that the instruments used are well within acceptable error bounds and that usage carefully follows manufacturers' recommendations. All measurements should be taken with utmost care and the result should simply be the best attempt to achieve the best estimation of flow using procedures and instruments that will yield the best chance for accuracy.

The level of accuracy of flow monitoring desired will directly influence the measurement technique that should be used and the overall cost of monitoring. This guidebook is intended to assist in the selection of the most appropriate flow measurement method for the typical situations encountered in South Florida, as well as procedures, proper operation, and determination and minimization of error.

FLOW MONITORING DEVICES AND METHODS

This section is meant to present a brief description of the four most common flow conveyance categories and appropriate methods of flow monitoring for them. More detailed discussions are available in the following sections. The four flow conveyance categories are: 1) pumps; 2) pipe flow in closed conduits; 3) open channel flow; and 4) open channel flow in the presence of a hydraulic structure.

PUMPS

Pumps are machines that increase the hydrodynamic head of fluids (lift, increased pressure, and/or increased velocity). A pump installation is necessary anywhere water movement by gravity is not adequate. Essentially, the act of pumping is the addition of energy to a fluid. As seen in Bernoulli's Equation (3), total energy (or hydrodynamic head) of water is made up of elevation, pressure, and velocity components. Any of these energy levels can be raised using a pump. Pumping also can ensure that specific volumes of water are available at the discharge

point in relatively accurate amounts at specified times and at desired pressures. A motor, either electric or fuel, provides the energy that is transferred to the water.

Water enters a centrifugal or helical impeller of a pump through a suction line. The impeller is a single, or series of, propellers, vanes, or blades that are arranged radially around the shaft and may be held together by one or two circular plates. As the motor rotates the shaft at high speed exerting a torque, the water is whirled around as it enters the impeller. The angular velocity imparted to the water particles throws them outward onto the wall of the casing. The casing is built so that it leads water toward the exit pipe either by vanes or by its gradually expanding spiral shape. By proper design of the casing, the energy is imparted to the water by the impeller gradually changes into pressure energy. Impellers of large radius and narrow flow passages transfer more energy per unit volume than impellers of small radius and wider flow-passages.

The selection of the type of a pump for a particular purpose is based on the quantity of discharge and hydrodynamic head needed. For example, the pump stations around Lake Okeechobee need to lift large quantities of water, but only a few feet. An overhead irrigation system's pump, on the other hand, would lift small quantities of water, but at much higher head. Turbine and centrifugal pumps are commonly used to extract water from wells and are generally classified as high pressure head systems. Axial flow pumps on the other hand, do not generate much pressure and are high volume, low pressure systems. All pumps are limited in their ability to lift water on their suction (inflow) side. This is why submersible pumps are used in deep wells where water levels are not near the ground surface. Pumps must be installed according to manufacturers' specifications to work properly and avoid destructive cavitation.

Essentials for Determining Flow Through Pumps

The most common method for determining flow through a pump is using its flow rating curves known commonly as "pump curves". Pump curves are provided by the pump manufacturer, but as the pump wears they must be updated by having a new pump calibration done. Pump curves provide the flow through the pump as a function of total dynamic head (TDH) and the pump's RPM. TDH is the height that the water is lifted from its source to the pump plus the outflow head (pressure) and the frictional head loss in the pipes. NOTE: The conversion factor between head (feet) to pressure (pounds per square inch or psi) is 2.31 feet/psi. Therefore to determine

flow by this method you must record both the TDH and RPM of the pump. To obtain TDH the inlet water level and outlet pressure or water level must be measured. An RPM meter is required for fueled motors while electric motors usually have a fairly constant known RPM. When pump power units are not directly connected to the pump drive shaft, or if gear sets are involved anywhere in the drive train, the motor RPM is not the pump RPM. In these cases, pump RPM would be determined by the ratio of pulley or gear diameters attached to the motor and the pump. Because water levels, pressures, and RPM can change through a pumping cycle a method is needed to directly measure or estimate these parameters throughout the pumping cycle.

Pump curves are provided in graphical sets (head versus discharge) for different pump rpms. It is possible to describe pump curves mathematically in the form of an equation so that flows can be calculated directly by computers or data logging instruments.

Alternatively, flow measurements can be made by an installed flowmeter. Typically, flowmeters are easier to use than the pump curve method because they typically provide a direct reading of flow. However, they can be expensive, particularly for larger pumps. A description of the most common flowmeters is in the following discussion on pipe flow. Further, descriptions of a wide variety of flowmeters are included in Section D.

For pumps, the accuracy ranges due to various reasons, including pump performance changes, intake clogging, flowmeter errors, and head and rpm measurement errors. Pump performance and flowmeter operation be checked on a regular basis (recommended every 5 years) for accuracy by running partial calibrations to ensure that rating curves are still accurately reflecting heads and flows. If not, recalibration is necessary. Further, any change in pump station configuration, power unit, drive system, inlet configuration, or outlet configuration may require a new rating curve.

Pumps as Siphon Devices

Siphoning is an alternative mode of operation where a pump is used to fill a pipe and then is turned of. The pump bore is then allowed to backflow, or siphon, by gravity from the higher stage side of the pump to the lower stage side. This type of use is rare and typically limited to low head axial flow pump systems. Back siphoning can be damaging to most other systems and therefore, may require backflow prevention. A flow rating curve must be developed using a flow measuring device.

PIPES

The measurement of flow in a pipe requires a measurement device to be installed. Several such devices are briefly discussed below. They are listed in order of the more commonly used

methods to those that are rarely used. Each method has its pros and cons and can be used as either a primary device or a device for verifying other flow measurement techniques such as the pump curves described above.

Trajectory and Vertical Flow into Open Air Methods

Although these methods are often looked upon as archaic and inaccurate, both methods have been calibrated and tested enough to ensure 85 to 100% accuracy. Whether water is leaving a pipe in a horizontal trajectory (horizontal) or in a fountain pattern (vertical), the characteristics of the outflow stream are dependent on the fluid properties, the pipe properties, gravity and the force that the water leaves the pipe. These parameters are generally stable, repeatable or constant, making flow approximations quite accurate.

For the horizontal pipe trajectory method, necessary measurements are the pipe diameter and the horizontal (x) and vertical (y) distances that the water trajectory follows from the centerline of the pipe to a datum (usually the ground or receiving surface). Simplifications to the process have been made, enabling the user to measure flows based on the distance from the top of the pipe to the top of the water trajectory 12 inches below the top of the pipe (Colt Industries Hydraulic Handbook; Pump Handbook, Krassik, ed.; USBR Water Measurement Manual). For full flow conditions, this method is often referred to as the Purdue Method. For partially full flow, the method is referred to as the California Method.

For the vertical pipe, necessary measurements are the pipe diameter and the height of the fountain of water being discharged (Colt Industries Hydraulic Handbook; Pump Handbook, Krassik, ed.).

Either equations or tables of calculated values can be used do determine flow. Both are included in the references above or other flow measurement handbooks.

Differential Pressure Flowmeters

Inline flowmeters that use a pressure drop through a flow restriction (reduced cross-sectional area) to measure flow are very reliable and have the advantage of no mechanical parts to fail or catch debris. Their disadvantages are relatively high cost and the slight loss of head within them. Common types of these meters include venturis, orifices, and nozzles, with the venturi meter being the most common. The accuracy of this method is dependent on the accuracies of the pressure drop measurement and the measurement of the cross-sectional area of flow. The pipe should be flowing full under pressure. The meter must be located a sufficient distance from the pump, a pipe bend, or joint (>10 pipe diameters) such that turbulence is dissipated. These meters require head measurements to be taken upstream and at the throat of the constriction in the meter section (subtract to find the head difference). The meters can be configured using differential

head readings also. The principle behind the operation of these types of meters is the Bernoulli equation (3). These meters are arguably the most accurate of any device used to measure pipe flow (+/-1% FS for venturi meters, +/- 1 to 2% FS for nozzles, and +/- 2 to 4% FS for orifices) (Karassik et al., 1976; www.engineeringtoolbox.com/49_590.html). Venturi meters are often

used in conjunction with large weighing boxes for laboratory flowmeter calibrations. Maintenance is minimal, there are no moving parts, and they cause very little head loss. The meters come with a coefficient of discharge, a ratio of throat to inlet diameter, and the area of the throat section. With this information and the difference in head measured, flow can be calculated. There are various ways of measuring and logging the head differences over time including physical recording of manometer readings and pressure transducers with dataloggers. Recalibrations should be conducted according to manufacturers' specifications. These meters lose accuracy under low pressure applications.

Inline Mechanical/Rotary Flowmeters

Inline mechanical flowmeters with propellers, impellers, turbines, vanes or paddles are also physically installed inline like the pressure differential flowmeters. Again, the distance from a pump, a pipe junction, or a bend must be at least 10 pipe diameters and uniform full pipe flow must be occurring. These types of meters are simple to use and can provide cumulative flow directly, eliminating the need for dataloggers or frequent readings. Essentially, they are calibrated such that given the proper flow conditions and appropriate sizing, each turn of the device shaft represents a flow volume passing through that pipe section. These meters must be properly sized to the diameter of the pipe. Flow rate and flow totalizer readings can be measured and recorded electronically, mechanically or manually. These meters should be calibrated according to manufacturers' specifications and must be watched for debris buildup and proper operation regularly. Initial installation according to manufacturers' specifications is the most important factor in ensuring reliable monitoring. If all installation specifications are adhered to, accuracies are generally within +/-2% FS (www.omega.com/techref/table1.html).

Ultrasonic/Acoustic Flowmeters

Ultrasonic/acoustic flowmeters can be divided into Doppler meters and time-of-travel (transit-time) meters and are a member of the acoustic flowmeter category. The Doppler meter uses ultrasonic sound to measure fluid velocity by measuring the Doppler or frequency shift between the source signal and the reflected return signal bouncing off moving particles in the flow stream. The frequency shift between the transmitted and detected signals is directly proportional to the flow velocity. The meter sensors may be mounted inside a pipe or strapped around outside of the pipe.

Doppler meters are convenient to use because they can be attached to the outside of existing pipes, minimizing installation headaches. However, these meters require the presence of

particles or bubbles in the water to function, so they are not recommended in clean water systems. Nonuniform particle distributions in the pipe cross-section can yield incorrect mean velocity measurements. The meters are also sensitive to changes in fluid density and

temperature. Hence, while not viewed as being extremely accurate under many conditions, accuracies are accepted as being between +/-0.1 to 5% FS if mounted and used according to manufacturers' specifications.

Time-of-travel or transit-time acoustic/ultrasonic flowmeters are more robust than the Doppler meters, but are more expensive. Their main advantage is that they do not require particles in the fluid to work effectively. These meters can also be attached to the outside of existing pipes. The principle of operation is that a sonic signal travel time in the direction of flow to a receiving transducer will depend on flow velocity. A transmitter and receivers are placed on opposite sides of a pipe at about a 45-degree angle to the direction of flow. Travel times in the upstream direction are slower than those sent downstream. Using the difference in signal travel time, average velocity can be calculated.

Ultrasonic flowmeters are useful for continuous monitoring and recording during a pumping event as well as for calibrating pumping systems. Full pipe flow is required for these flowmeters to work properly.

Electromagnetic Flowmeters

Electromagnetic flowmeters for pipes operate on much the same principles as those for open channels. In this case, the meter itself consists of a nonmagnetic and non-electrical conducting pipe section. Two magnetic coils are place on opposite sides of the pipe section. Two electrodes are mounted on opposite sides of the pipe in a plane perpendicular to the magnetic coils. As flow passes through the meter, the electrodes pick up a voltage that is directly proportional to the flow velocity. The signal is amplified and translated into flow and volume measurements. These meters are accurate to +/-1% of the rated operating range when installed and used in accordance with manufacturers' specifications (www.badgermeter.com; www.usbr.gov/pmts/hydraulics_lab/pubs/wmm).

Pitot Tubes

The rate of flow in pipelines under pressure may be computed from the conduit cross sectional area and velocity observations made by a pitot tube. The device consists of a right-angle bent tube which, when immersed with the bent open ended part pointed directly into the flow, will provide a direct measure of total head (velocity plus static head). For flow in open channels, the velocity head will simply be the distance that water rises in the vertical stem of the pitot tube above the water surface. However, when flowing under pressure, the user must also account for the static pressure within the pipe that will be included in the pitot tube reading. In this case, the

static pressure head within the pipe must also be measured. This is done by using a static probe that is a simple tube with its opening(s) facing perpendicular to the flow so that it will not

measure any velocity head associated with the flowing water. Some probes will couple the tubes with the static pressure tube concentric around the velocity tube, with holes drilled in the static tube. The pitot-static pressure probe essentially consists of two separate, essentially parallel parts, one for indicating the sum pitot-static pressure and velocity heads (total head) and the other for indicating the pressure head. Subtracting the static pressure head from the total head yields the velocity head. The formula to calculate velocity is derived from the Bernoulli Equation and can be written as

$$V = [2g * (\text{total head} - \text{static head})]^{1/2} \qquad\qquad (4)$$

A manometer is the typical device used to measure the heads generated by the pitot tube and consists of one or two transparent vertical tubes. In its simplest form, the manometer tube is simply connected to the pitot tube probe such that the rise of water within the tube above the flow stream can be easily observed. For pitot-static tubes, two manometers are required, one for indicating total head and the other for the pressure head. Alternatively, a differential manometer (U-shaped) can be used to automatically account for the static pressure head. In this case, the velocity head is the difference between the water or mercury heights in the two legs of the manometer.

Since the pitot tube can only measure the velocity at one point in the flow profile, care is needed to account for varying velocities across the flow cross-section. For pipes, the mean velocity across the area of flow is best obtained by dividing the cross–sectional area of the pipe into a number of concentric, equal area rings and a central circle, measuring/calculating the velocity of each section, and then averaging the values. A standard ten-point system (four equal area rings and central circle) is commonly used. Flow rate is then calculated by multiplying the average velocity by the inside cross-sectional area of the pipe at the point of measurement.

In practicality, the pitot tube is probably not one of the best instruments for continuous monitoring because of velocity variability, clogging issues, and difficulty of accurately measuring continuous low heads. Its greatest value is for pump and flow calibration exercises. Use for continuous or event monitoring could be possible under explicit conditions. Those conditions are: 1) Pipe flow is extremely uniform and two readings are taken during an event to demonstrate uniformity; 2) A representative average flow velocity point within the pipe can be identified and substantiated under the range of flow conditions enabling more frequent or continuous monitoring; 3) A recording manometer is part of the monitoring system; 4) water is fairly clean such that blocking or clogging of the pitot tube is not an issue; and 5) the SFWMD preapproves the procedure.

Dye Fluorometry

There are two types of dye fluorometry methods that will yield pipe flow measurements. They are the tracer dilution and tracer velocity methods. Basically, tracer velocity is limited to use in high velocity pipe sections with definite mixing while tracer dilution can be used in both high and low velocity situations such as flow through culverts.

The tracer dilution method is based on the principles of mass balance. A tracer is introduced upstream at a measured rate and concentration. Downstream concentrations are then measured for a period of time at a point where complete mixing is ensured. Measurements continue until the tracer concentration becomes constant. The amount that the tracer is diluted in the flowing water is determined and can be related directly to flow rate.

The tracer velocity method is simply a measure of time that it takes a tracer to pass through a pipe. Again, the tracer is introduced upstream and downstream concentrations are recorded over time. Flows are then mathematically calculated from estimated velocity and cross-sectional area.

Dye fluorometry flow methods are generally accepted to be accurate to +/-2% using Rhodamine WT and a suitable fluorometer. While the methods are cumbersome for continuous flow monitoring during pumping events, like the pitot tube, it is an excellent flow measuring choice for calibrating pipe flow systems.

Other Methods for Pipe Flow Measurement

There are many other meters and methods for measuring or estimating pipe flow velocities and volumes. The methods will generally fall under one of the above discussed categories. Their exclusion in this discussion does not intend to preclude them as viable means to accurately estimate water flow in pipes. Rather, the methods or meters are generally less popular, more cumbersome, more expensive, closely related to, and/or more complicated than this program merits. However, some estimation methods such as the California Pipe method may actually be suitably accurate in certain applications. Others such as the volume collection or tipping bucket type methods may actually be suitable, more accurate, and less expensive than the methods discussed for certain applications. Finally, some of the methods discussed are expected to be used in continuous flow monitoring applications while others are more suited for point-in-time measurements to verify rated pump system performance. While the latter seems to be less accurate than installing a continuous flowmeter, this may simply not be the case. The user should check with the SFWMD prior to installation and use of the unmentioned methods.

OPEN CHANNEL FLOW

This section is broken down into flow in the absence of designed flow management/monitoring structures (streams or channels) and flow in the presence of designed flow management/monitoring structures (weirs, culverts, gates, etc.). Instrumentation, monitoring procedures and verification (calibration) exercises are virtually the same for both conditions, with structures simply providing a higher level of accuracy because of a clearer definition of a channel cross-section. However, some structures may not require any calibration because they can serve directly as reliable flow measurement devices since flow through them can be directly calculate based on heads and the physical parameters of the structures.

Absence of Hydraulic Structures

Flow through an open channel or stream when no hydraulic structures are present can be estimated by use of the Manning formula (Equation 2), a stream rating curve, streamgaging, or dye fluorometry. Unfortunately, the Manning formula is very difficult to use since it is extremely difficult to reliably measure the hydraulic slope under natural conditions and cross-sectional area is often not well defined. Therefore, for routine flow monitoring, the Manning formula and its related derivatives is probably not a very reliable method.

The stream rating curve method requires that a relationship between flow and stage be developed through a detailed streamgaging process. For the low gradient systems, such as those found in South Florida, the stream rating curve method is not very reliable and is not recommended.

Velocity meters can also be used in association with stage to cross-sectional area relationships to estimate stream flow. Either magnetic, mechanical, Transit-Time, or Doppler type meters can be used, however these are fairly expensive alternatives for continuous measurements because of high installation costs and high maintenance requirements. However, these meters are excellent for short-term measurements associated with calibration of other measurement techniques. This short-term approach is referred to as area-velocity/streamgaging and is discussed in greater detail below.

Dye fluorometry is also only appropriate for calibration purposes, but can be very useful for situations of stream geometries that are difficult to handle by other techniques. This and other alternative methods are also discussed in greater detail below.

Float method

In many applications, the most inexpensive methods for flow measurement are the best since they ensure that the measurements will be taken and with due diligence. The float method, while not simple, provides an inexpensive method for approximating flows

(www.fish.washington.edu/naturemapping/water/3monflw.html). If used properly, and in situations where flows are generally uniform and within relatively narrow upper and lower bounds, the method can produce excellent results.

The float method requires the determination of the cross-sectional area of flow along a channel section that does not change greatly. Streamgaging techniques are recommended. Given the measured area, the user then measures the flow rate in the channel section using floating objects spread out on the water surface. The time it takes the floating objects to go a certain distance is the average water surface velocity. It is recommended that the average velocity be multiplied by a 0.8 correction factor to account for the shape of the velocity profile from the surface to the channel bottom (Dunne, T. and L.B. Leopold, 1978). This method should not be used in turbulent channels, in channels with greatly varying cross-sections over the test length, or on windy days when the water surface velocity can be skewed forward, backward or sideways.

Area-velocity/streamgaging

In the absence of a hydraulic structure in an open channel, the channel bottom shape itself defines the cross-sectional area of flow in the flow equation (1). Determination of the cross-sectional area of flow can be a cumbersome procedure when accuracy is desired. After defining the area, adequate measurements to determine the average velocity of flow through the cross-section must be made to calculate the flow rate. This activity is also referred to as streamgaging.

To obtain reasonable values for flow, the channel will need to be divided up into several vertical sections across the channel, generally of equal width. The area of the vertical section is then calculated. The area of each vertical section will then need to have an average velocity determined for it. The more vertical sections that the cross-sectional area is broken down into, the better the accuracy of the flow estimation. In the middle of each vertical section, a depth to channel bottom will need to be measured. Then, using any one of a number of current meters (electromagnetic, anemometer and propeller, Doppler, optical strobe), a representative flow velocity for the vertical section is determined. Achieving a suitable average velocity can be done using one of several standard practices (two-point method, six-tenths method, three-point method, etc.). Further discussion about current meters and acceptable average velocity measuring techniques are in Grant, 1992 and www.usbr.gov/pmts/hydraulics_lab/pubs/wmm.

After determining the average velocities and areas for all vertical sections, the trapezoidal rule is used to sum up the total flow through the channel cross-section.

For routine monitoring of flow, this method is cumbersome and simply not applicable. However, if time is spent to gage the stream enough times and to locate an approximate point of average flow velocity for the channel under different depth and flow conditions, a cross-sectional area of flow versus depth relation can be developed. Then, mounting a current meter at a point in the channel that has been determined to be representative of the average flow velocity, channel stage and single point velocity readings can be taken and automatically recorded during flow

events to yield an accurate discharge rate and volume. However, due to price considerations, the sensitivity of the equipment and instrument mounting requirements, this method is not recommended. Measuring flows in this manner should be limited to pump and hydraulic structure calibration exercises.

In addition to the constraints listed above, stream gauging is only recommended and accepted as a calibration data collection method in situations where 100% of the flow to the pump is through the single channel being measured. Low velocities, non-uniform channels, interference from side channels, fluctuating water levels during data collection are some of the conditions that will interfere with accurate discharge measurements. While it is advised that upstream channel sections be monitored, at times it may be prudent to go to a channel section downstream of the pump station to avoid side channel interference and backflow through leaky pump stations as is common in box pump configurations where the primary purpose of the pump station is to move water laterally (as opposed to vertically) on or off a property. In this case, it is required that the channel stage between the pump station and the cross-section selected for measurement is demonstrated to not be accumulating storage (constant stage; a pressure transducer mounted in the channel can provide a continuous record of stage during measurements).

Current/Velocity Meters for Streamgaging

Vertical axis or vane type current meters (Price AA) and electromagnetic meters (Marsh-McBirney) are two of the most often used current/velocity meters. A vertical axis meter consists of a wheel that rotates when immersed in flowing water and a device for determining the number of revolutions of the wheel. Water velocity is determined by counting the number of revolutions of the wheel over a given period of time. The relations between the velocity of the water and the number of revolutions of the wheel per unit of time for various velocities are determined for each instrument by U.S. Bureau of Standards and are supplied in the form of an equation from which a rating table is compiled.

An electromagnetic meter operates on the principle that a voltage is induced in an electrical conductor moving through a magnetic field. For a given field strength, the magnitude of the induced voltage is proportional to the velocity of the conductor (flowing water). The sensor is equipped with an electromagnetic coil that produces the magnetic field and a pair of electrodes that measure the voltage produced by the velocity of the flowing water. The measured voltage is then processed by electronics and output as a linear measurement of velocity.

There are other types of current meters for measuring water velocity, these include the Acoustic Doppler Current Profiler - ADCP, the Point Acoustic Doppler Velocity Meter - PADVM and the Smart Acoustic Current Meter SACM.

The acoustic Doppler current profiler (ADCP) and point acoustic Doppler velocity meter (PADVM) operate on the principle of the Doppler effect of sound moving in water. The meters send a series of phase-encoded acoustic pulses at fixed frequency along each of the narrow

acoustic beams and measures the frequency shift of the return echo. The ADCP is suspended in a fixed position within the water column and continuously measures velocities at user-prescribed intervals from near the channel bottom to near the water surface as the meter is moved across the channel. The point acoustic Doppler velocity meter (PADVM) measures a discrete velocity near the transducer heads and must be moved laterally and vertically within the measurement section (similar to a Price AA meter) to determine mean channel velocity. Velocities as low as 0.03 ft/s can be measured using the ADCP and PADVM.

The smart acoustic current meter (SACM) is a vector averaging current meter. The SACM is based on the time of travel of acoustic signals sent between two pairs of transducers oriented diagonally across the flow path. A small reflector located about one inch below the acoustic transducers reflects an acoustic pulse from one transducer to the opposite transducer. Components of the velocity vector are resolved using the velocities measured along the two acoustic paths and an internal, magnetic compass. The SACM can measure point velocities as low as 0.03 ft/s.

Factors to be aware of when using current meters are:

- Metering equipment must be used within the manufacturer's guidelines.
- Eighty percent (80%) of the point velocities measured must be above the manufacturer's minimum velocity.
- The two-point method and six-tenths-depth method of determining mean velocity in vertical line should be used. Meter measurements should be taken at 2 and 8 tenths depths if the depth of flow equals or exceeds 2 feet, otherwise at the 6 tenths depth.
- No velocity measurement section shall carry more than 10% of the flow.
- The U.S.G.S. standard 40 second minimum observation time should be used
- Approach velocity measurement sections must be taken near the pump but no closer than a main canal width form the pump station and at least a main canal width downstream from side canals in a reach characterized by uniform flow and no turbulence. Artificial and/or temporary blocking of side or tributary canals is not representative of actual field operating conditions thus is not recommended.
- The meter shall be uniformly calibrated according to manufacturer's criteria.
- The meter must be visually inspected often to ensure physical integrity.

Dye fluorometry

There are two general dye fluorometry techniques used in open channel flow: 1) the velocity-area method; and 2) the tracer dilution method. For the velocity-area method, discharge is calculated using

$$Q = \frac{AL}{T} \tag{5}$$

where Q is in ft^3/s, A is the average cross-sectional area of the reach length in ft^2, L is the length of channel between the detection stations in ft, and T is the time required for the tracer to travel between the detection stations, s. This method is NOT appropriate for open channels.

For the tracer dilution technique that is appropriate, discharge is calculated using

$$Q = \frac{q*(C_1 - C_2)}{C_2 - C_0} \qquad (6)$$

where q is the discharge rate of the concentrated solution being injected into the stream, C_0 is the background concentration of the tracer in the channel, C_1 is the concentration of the injected tracer, and C_2 is the concentration of the tracer at the downstream sampling station where complete mixing has occurred. Note that the tracer-dilution method does not require channel geometry or time measurements. Rather, the method depends on dilution concentrations and fully mixed conditions to occur downstream. The injection flow rate provides the volume per time dimensions for Q.

Tracer methods are quite accurate, but depend on a host of parameters to hold their accuracy (+/- 1% to over 30%). The primary factors for accurate measurements are the use of a well-calibrated fluorometer with a high accuracy rating and complete dye mixing in the stream segment being monitored. Another consideration is that the chemical tracer used must be stable in the environment in which it is used, i.e. it cannot fade in sunlight or be adsorbed by bottom sediments or biological growths. Backflows and eddies in the channel will delay the dye movement and impede the necessary mixing. Therefore, upstream dye injection must continue until the downstream concentration stabilizes at a constant value at all points across the flow path. The user is referred to nationally recognized procedures and guidelines such as those in the American Society of Mechanical Engineers Performance Test Codes for guidance to achieve accuracies desired in this program.

As with the streamgaging methods, dye fluorometry techniques are not readily suited for continuous monitoring during flow events. The methods are more suited for pump station calibration exercises or to check the accuracies of other methods used.

Tracer dilution method considerations:

- Determine whether slug or continuous injection of a tracer should be used and develop appropriate tracer measurement plan.

- Ensure the tracer is uniformly mixed within the sampling section. Injection manifolds may be needed to help achieve mixing.

- Instrumentation must be maintained and calibrated according to manufacturer's recommendations. Care must be taken to ensure that dye-water samples are within the linear range of a fluorometer and that background fluorescence is taken into account.

Other flow measurement methods

The use of any other data collection method not identified in this document will require prior approval from the SFMWD. Some manufacturers have designed instrument systems combining depth measurement with a point-velocity sensor. The velocity in the flow stream is measured at one point, typically the bottom of the channel, and the point velocity is converted into an average stream velocity based on stored calibration data. The average velocity is then used with the measured depth to determine the flow rate in the stream. Because of the complexity, expense these devices, and the short history of in-field testing for reliability and accuracy, these devices are not widely used.

Presence of Hydraulic Structures

For the purposes herein, hydraulic structures are defined as any structure that can be used to divert, restrict, stop or otherwise manage the flow of water. They can be made from a variety of materials including concrete, steel, rock, asphalt, wood and earth. Water control structures include pump stations, weirs, flumes, gates and culverts. When a hydraulic structure is present, flow monitoring and calculation is often simplified and more accurate since the structure provides a definite and measurable cross-sectional area of flow. Further, many structures are designed to enable the monitoring of flow by forcing unique flow conditions to occur in a cross-section, requiring that only relatively simple head measurements be taken on a regular basis to estimate flow. In other words, the function of some hydraulic structures is to produce a flow that is characterized by a known relationship (usually nonlinear) between a water level measurement (head) at a particular location(s) and the flow rate through the structure. This relationship or head-flow rate curve for the particular structure or device is called the structure rating curve. A hydraulic structure designed to monitor flows is referred to as the primary device while the change in water level is measured by a secondary device. Many electronic dataloggers associated with the secondary device can also automatically convert the water level readings to a flow rate using preprogrammed equations. Weirs and flumes are intentionally installed to enable flow monitoring while culverts and gates are flow control structures that yield known flow geometries and can be adapted to flow monitoring.

Weirs

A weir is an overflow structure built across an open channel to raise the upstream water level so that water flows over the weir's top edge (a well-defined cutout section). The lowest point of structure surface or edge over which water flows is called the weir crest and the stream of water

that exits over the weir is called the nappe. The depth of the flow over the crest is called the head and can be directly related to the flow going over the weir.

A properly installed weir has a shape and orientation that provides a unique depth of water in the upstream pool for a given discharge. Hence, they can be flow rated using the upstream head relative to the crest height. The shape of the cutout determines the crest overflow shape, which in turn governs how the discharge varies with head. Head-discharge equations are then used to calculate flows. Weir equations and crest coefficients for common weir geometries are available in most hydraulic books.

Weirs can be characterized in a number of ways, each resulting in the need to adjust the weir equation. Contracted weirs are characterized by notch sides that are narrower than the channel and crest heights sufficiently above the channel bottom. This configuration results in flow paths that converge through the cutout from all directions. A suppressed weir is one in which no side contraction of the flow stream exists. Partially contracted weirs result when specified distances of the cutout sides or bottom from the channel sides and bottom are not met.

In addition to contracted and suppressed weirs, weirs can be identified as either sharp-crested weirs or broad-crested weirs. Sharp-crested (or thin plate) weirs are thin plastic or metal plates set vertically across a channel and perpendicular to the flow. They have sharp upstream edges formed so that nappe flows clear of the crest. Sharp-crested weirs are partially named by the shape of the blade overflow opening, such as rectangular, triangular (V-notch) and trapezoidal (Cipolletti). A broad crested weir is a structure that supports the nappe for an appreciable distance in the direction of flow.

Each type of weir has a specific discharge equation for determining the flow rate through the weir. The equation is based on the depth of the water in the pool formed upstream from the weir. A weir discharge measurement consists of measuring depth or head (height of the water above the crest) relative to the crest at the proper upstream location in the weir pool, and then using a table or equation for the specific kind and size of weir to determine discharge.

Flow over weirs can be classified as free flow (unsubmerged) or submerged. In free flow, air has free access under the falling jet or sheet of water (nappe) exiting the (weir crest) cutout. When downstream water levels rise above the weir crest elevation, submerged conditions exist. This condition requires a correction to be made to the weir equation. When submerged conditions exist, flow measurements, even with submerged condition calibrations, should only be viewed as flow approximations since accuracy falls off dramatically.

Weir flow equations are generally of the form

$$Q = C*L*h^{3/2} \tag{7}$$

where Q is the discharge in ft^3/s, C is a discharge coefficient, L is the length of the weir crest in ft (unity for triangular or V-notch weirs), and h is the head above the weir crest in ft of water. Discharge coefficients and tables of precalculated flows for different geometries and flow conditions are available in various hydraulic references.

Flows estimated from weir relationships can have accuracies as good as +/-1.5% to 2.5% if care is taken to follow proper protocols and manufacturers'/design specifications (www.usbr.gov/pmts/hydraulics_lab/pubs/wmm). However, it must be noted that the accuracy of head measurements will introduce further error. Plus, any clogging of, or structural damage to, the weir can also introduce significant error. For standard weir geometries without submergence problems, calibration is only required for the water depth measurement instrument selected. However, for non-standard geometries calibration of the weir using streamgaging techniques is recommended.

Weir Considerations

- construction must be precise and according to specifications
- installation must be normal to flow path and crest must be level (centerline of V vertical for V-notch configurations)
- adjust weir crest coefficient based on the crest width in the flow path
- the most accurate condition is a sharp crested weir whose crest thickness is between 0.03 and 0.08 in and uniform over the entire overflow edge
- upstream edges of the weir opening must be straight and sharp but not knife-edged
- supporting bottom and side edge plates should be no closer to the crest than twice the maximum head expected at the crest
- nappe should touch only the upstream side of the crest
- downstream water surface should always be at least 0.2 ft below the crest
- measurement of head on the weir is the vertical distance between the crest and the water surface upstream a distance of at least four times the maximum expected head on the crest
- approach to weir must be kept free of sediment deposits and surface debris build-up

Additional V-notch weir considerations

- design for full contraction if at all possible since only the 90 degree configuration can be partially contracted
- maximum measuring head should be 1.25 ft
- average width of the approach channel should always be greater than 3 ft
- V-notch bottom should always be at least 1.5 ft above the invert of the weir pool

Additional trapezoidal (Cipolletti) weir considerations

- height of the weir crest over the bottom of the approach channel should be at least twice the maximum head expected over the crest
- Distances to side of channel from cutout should also be at least twice the maximum head expected
- heads should not be less than 0.2 ft or greater than one-third the crest length unless specific calibrations are done for those conditions

Broad-crested weirs essentially follow the same principles as long-throat flumes when submerged. Accuracy of measurement is nearly as good as sharp crested weirs for unsubmerged conditions. Some advantages, however, do exist. For example, broad-crested weirs can be computer calibrated (crest coefficient estimated based on width), maintenance problems that could occur with the weir plates are eliminated, these weirs can be designed for more complicated channel geometries, floating debris and sediment become less of a problem, and submergence is less of an issue.

Flumes

Flumes are artificial channels with clearly specified shape and dimensions that constrict and accelerate the flow through them. They are primarily designed for measuring flows that vary widely such as seasonal runoff, but can also be used for continuous monitoring. The area or slope (or both) of the flume is intentionally different from that of the channel, causing an increase in water velocity to "critical", which creates an associated drop in water level that is proportional to the rate of water flowing through the flume. This "critical" flow condition is created by gradually reducing the width of the flume at its midpoint while the flume bottom is either raised or lowered in such a way that critical flow occurs. Note that when only the bottom is raised with no side contractions, the flume will function as a broad-crested weir. Because critical flow is attained, measuring the upstream water level allows discharge to be accurately computed.

The most common types of flumes are the Parshall flume, and the trapezoidal flume. The Parshall flume is the most widely known and used flume. It consists of a converging upstream section, a throat, and a diverging downstream section. Parshall flumes constrict horizontally and are designed for rectangular or trapezoidal channels. As water enters the flume, it converges in a restricted section called a throat. At the same time, a drop in the floor at the throat causes a change in the flow depth.

A Trapezoidal flume consists of a wide approach section, a gradual transition section, and a throat section. The flow through a trapezoidal flume is computed by estimating the discharge through the critical depth at the throat.

Other popular flume types are the H, cutthroat and Palmer-Bowles. For all flumes, head measurements in the throat or at upstream and downstream locations will need to be made. Flumes are empirically calibrated and flow equations take the form of

$$Q = C*h^n \qquad\qquad\qquad (8)$$

where Q is the flow rate and C and n are empirical curve fitting parameters. Values for C and n are tabulated in hydraulic handbooks for different flumes and different sizes. Further, corrections for submergence are also presented in tabular or graphical form. Commercially available flumes are supplied with the appropriate equation. However, as long as appropriate flow conditions occur in the throat sections for the range of flows expected, calibrations can be conducted using streamgaging methods. Expected accuracies can be within +/-5%.

Special considerations for flumes

- standard flumes require no calibration whereas non-standard shapes will
- should not be located near turbulent flow, tranquil flow is best
- while not recommended due to considerable accuracy drops, flumes can be designed for up to 95% submergence
- 65 to 85% submergence is currently recommended as a maximum
- sufficient head loss through the flume is necessary to enable accurate head measurements
- accurate workmanship is necessary in order to ensure reliable performance
- placement and installation criteria are the same as for weirs
- head can be measured in the flume or in a stilling well set off to the side
- staff gages and mechanical float recorders will suffice for occasional measurements, but other more sensitive measurements can be achieved using pressure transducers or potentiometric, capacitance, conductance and sonic devices
- long-throated flumes can achieve errors less than +/-2%

Culverts

A culvert is a closed conduit for conveyance of water. This type of water control structure provides a means for water to pass underground from one location to another. The traditional use of culverts is to convey storm water flow under access roads without causing excessive backwater buildup or overtopping, while minimizing downstream velocity.

Culverts are commonly made of metal (aluminum or steel), reinforced concrete, or PVC. The concrete may be either circular or rectangular in cross section. When it is rectangular, the culvert is usually referred to as a box culvert. The major components of a culvert are its inlet, the culvert pipe barrel itself, and its outlet. The metal and PVC culverts are typically corrugated for additional strength.

There can be four states of flow through an open culvert, which depend on the up and downstream heads, culvert dimensions, and its bottom slope. These flow states are: 1) inlet orifice controlled (requires high upstream head and low downstream head); 2) inlet weir controlled (upstream head below top of culvert, low downstream head, and significant bottom slope); 3) pipe controlled (up and downstream heads above culvert); and finally 4) open channel controlled (partially filled culvert with downstream backwater where the Manning's Equation controls). The low head drops (by design) through a culvert and these different states of flow that can occur sometimes make it difficult to use culverts for flow measurement. Often culverts are associated with other structures such are weir or gates and in these cases these structures are would typically provide a better flow measurement location and are discussed separately in this guidebook. However, two common structures that are attached to culverts are briefly discussed below.

Gated culverts provided control of culvert flow using slide gates. The design maximum discharge for the culvert assumes the gate(s) are completely open or do not restrict flow. The configuration of the inlet may be flush against a headwall, projected into the approach channel, or angled to a wingwall. Provisions are sometimes made for reverse flow.

Flashboard risers are more commonly used tan gates for culverts. This moveable board system allows upstream water levels to be controlled by the number of boards placed in the riser. With flashboard risers, water is forced to flow over the top of the board(s). Raising the water level can create a low flow area just upstream of the riser that facilitates deposition of sediments and their accompanying nutrients or pesticides. Flow through culverts with flashboard structures is typically controlled by the weir formed by the boards. However, at high up- and/or downstream heads, there is a possibility that the flow could still be controlled by pipe flow through the culvert.

Flow Computations for Culverts

As previously indicated, using flow through a culvert as a primary monitoring device can be difficult and is typically not recommended unless it is the only available structure in the flow system. If it is known that the culvert will be under full-conduit flow (pipe flow) or open channel for most conditions (typical case for south Florida) then use of the open channel flow measurement options all apply to culverts where the cross-sectional areas is well defined.
In many cases, pipe and open channel flow will occur through a culvert interchangeably. In these cases, the head reading must be used to switch between computational methods or an integrated computational method can be developed.

Gates

Various types of gates are used to control flow. Virtually any gate structure can be used as a primary flow measuring device if the structure is of a standard geometry or is properly

calibrated. Flow through gate openings is typically controlled by orifice flow conditions. This means the flow through the opening is proportional to the head difference between the two sides of the gate as shown in the following equation:

$$Q = C*A*(2gh)^{1/2} \qquad\qquad (9)$$

where C is a collection of coefficients specific to the gate geometry and flow conditions, A is the cross-sectional area of the gate opening, g is the gravitational constant and h is the head difference across the gate. C coefficients are available for many standard gate structures that can be purchased commercially, but these coefficients are only valid if the structure is installed in accordance to the manufacturers' recommendations. For non-standard gate structures, an in-field calibration will be needed. This calibration requires upstream and downstream heads across the gate and corresponding flow measurements (see streamgaging). The range of head conditions and gate openings expected should be covered by the calibration exercises, yielding a family of curves that should then yield a single C coefficient. In some cases, the C coefficient can vary as a function of gate opening, so care is needed. Also, the orifice flow assumption is invalid if the upstream water surface is not above the top of the gate opening. In this case the gate opening will act as a weir.

Secondary Measuring Devices for Water Levels

As discussed above, the rate or discharge through a primary measuring device such as a weir, flume, culvert, or gate, or in an open channel, is a function of the water level in or near the primary measuring device. The secondary measuring device provides the water level(s) or head(s) that are required to calculate flow from the primary measuring device's rating curve or flow. Modern dataloggers can log heads and perform calculations for flow velocity, flow rate and totalized flow volume.

The following are some more commonly used methods for water level measurement.

Staff gage

Every installation should include a staff gage from which the height of the open water may be determined. The datum or reference elevation for the staff gage should be determined prior to installation. Typically, the datum is set to either mean sea level (MSL) or the stream or structure bottom. Staff gages provide fast, visual indication of water level. The user should choose a staff gage that is environmentally rugged. Typically they are made of porcelain enamel covered steel. Staff gages are not appropriate in cases where continuous monitoring is required. However, they should be installed because they are the best and easiest way to verify the proper functioning of other continuous recording devices. They do have usefulness when flow rates are large and flows are considered to be constant and consistent requiring few head measurements to achieve

suitably accurate flow volume estimates. Applications are common for large axial flow pump stations and for open channel structures.

Float-pulley stage recorders

The float gage is a simple, inexpensive, yet practical means of automatically indicating water levels in canals, rivers, flumes and other uncovered conduits. The operating principle is simple in that a graduated tape or beaded cable, with a counterweight on one end and a float on the other, is hung over a pulley.   The float moves the tape or cable up or down as the water fluctuates, thus rotating the pulley. Many of the instruments available have basic strip chart recorders. Some float pulley systems use potentiometric devices to eliminate strip charts and enable electronic datalogging. The float-pulley system has been the mainstay of head measuring devices for years. What it gives up in instantaneous accuracy, it gives back in overall reliability. Common applications require a stilling well or basin to limit unnecessary float movement that yields "noise" or false readings. Float-pulley systems are common for flumes and weirs, but can be used effectively for any of the open channel flow methods.

Electrical

This type of level measurement system uses some sort of change in electrical current caused by a changing water level to indicate the head. Most designs use a capacitive or resistance type probe or strip.   The resistive tapes have become very reliable and extremely useful for tight applications such as wells. These methods require dataloggers and power supplies.

Ultrasonic

The liquid level is measured by determining the time required for an acoustic pulse to travel from a transmitter to the liquid surface (where it is reflected) and returned to a receiver. These can be designed for above water surface or subsurface applications. Dataloggers are required.

Bubbler

A bubbler tube is anchored in the flow stream at a fixed depth, and the tube supplies a constant bubble rate of pressurized air or other gas. The pressure required to maintain the bubble rate is measured; this pressure is proportional to the water level.

Pressure transducer

A pressure transducer contains a strain gage that converts water pressure changes to changes in electrical resistance under a constant voltage. The pressure transducer is mounted below the lowest water level expected and referenced to a point that enables the appropriate head measurement to be made. The pressure transducer requires a power supply and datalogger.

Measurements are accurate, continuous monitoring is possible, sensor longevity is excellent, but costs are relatively high.

Final Note on Accuracy

The measurement of open channel flows can never be other than a study in best approximations. No absolute values can be obtained. If accuracy is attained under one set of conditions, in the laboratory for example, those results will not apply if the conditions of subsequent use depart from those of the laboratory. No carefully controlled laboratory measurements can ever be exactly duplicated in the average field installation. Under normal field conditions, errors on the order of +/- five to fifteen percent should not be unexpected. Further, techniques for verifying accuracy of primary devices have their own associated errors, making it difficult to ascertain whether calibration exercises are accurate enough to merit taking action. Hence, if methods are employed according to specifications provided by a reliable company or organization, and the basic instrumentation collectively has laboratory errors that are no greater than SFWMD requirements, a method should be acceptable for compliance monitoring. Any person performing calibrations or audits must acknowledge the errors associated with the calibration method and make them part of their overall error estimate for the flow measurement method.

MAINTENANCE AND CALIBRATION CONSIDERATIONS

Regardless of what system is selected for flow monitoring, maintenance is of the utmost importance. All flowmeters, primary measurement structures and secondary measurement devices must be checked to ensure that they are clean and undamaged. Maintenance logs should be kept to ensure that the user is performing the necessary checks. All instruments should be cleaned after each use and intermittently during use if the need arises. Culverts, gates, weirs and flumes should be checked for geometric integrity on a regular basis since changes in form (bent cutouts, partially crushed culverts, gate restraints losing the ability to produce a repeatable opening, etc.). Additionally, sediment buildup at inlets or outlets should be cleared, as should aquatic macrophytes.

All monitoring systems should be calibrated on a regular basis. For meters and flow measurement devices, manufacturers' recalibration recommendations should be followed. Recalibrations on a more frequent basis will be necessary depending on the conditions of use and diligence of care. Pump calibrations should be conducted on a five-year basis, or anytime a repair or change is made to the motor, pump or pump station configuration. Recalibrations can be as simple as checking two head-discharge points with the previously developed rating curve. If the points are within +/-5% of the rating curve and show no obvious pattern (for example if both points fall above the rating curve), then it may be assumed that the previous rating curve is accurately reflecting pump flows. The same "test" can be used for recalibration and testing of any of the rating curves for any of the devices used in open channel flow measurement. Note

that if rating curves were developed for more than one rpm setting, that curve should also be tested for accuracy. It must be cautioned that in the case of hydraulic structures, changes in the rating curve are generally caused by a change in the primary measuring structure geometry. Hence, simply developing a new rating curve will not suffice until the appropriate repairs are made. Any repairs must be made consistent with the proper requirements of the structure

SELECTION OF MONITORING AND CALIBRATION METHOD

The selection of a flow measurement/monitoring method must include the selection of a calibration method as well. Many of the applicable continuous monitoring devices discussed may also be used for calibrations. One should be aware that in most cases, in-field calibration tools are just as accurate or inaccurate as the method in place. Hence, there will always be some uncertainty about whether calibration values merit a full recalibration or equipment replacement.

Selecting appropriate monitoring and calibration methods is not an easy task. Often, in field situations water delivery systems are simply not ideal and require a user to adapt technologies. In short, theoretical and laboratory designs, assessments and recommendations are not typical of field installations. Hence, users and regulators must be prepared to hybridize methods under certain applications. Likewise, when new delivery/pumping systems are being designed, they must consider the monitoring requirements in their design and installation.

When making the appropriate system selection, a user must account for several factors. These factors include cost, accuracy requirements, regulations, range of flow rate, head loss, site conditions, likely operating conditions, types of records required, quality of the flow stream, system longevity, maintenance requirements, construction and maintenance requirements, calibration requirements, user acceptance, and vandalism potential. As can be seen, the types of factors to consider fall into two main categories; physical and operational. A brief discussion of some of the most important system selection factors is presented below.

Accuracy

Most water measuring devices can provide accuracies of +/-5%. Many are touted as being accurate to +/-1%. It is important to note that these accuracies are under ideal conditions and that the higher accuracies generally reflect laboratory conditions. To attain the higher accuracies, special construction, recalibration, maintenance, operation, etc. will be necessary at great cost. That cost will often eclipse the benefit of the procedure, and is hence, not recommended. However, if devices are properly selected and manufacturers' recommendations for operation are followed, +/-5% accuracy should be attainable under ideal field conditions. This yields assurance to regulators that, even under non-ideal field conditions, +/-10% accuracy is reasonable to expect. However, there are outlier cases where site conditions will simply not enable accuracies of less than +/-10% to be achieved.

Accuracies are generally reported for primary measurement devices. When secondary measurements are necessary, error is typically added to the system. For example, a flume or weir is rated with a certain accuracy. But, unless that accuracy was reported with a packaged head monitoring device, the user must account for both the structure as well as the head monitoring device. The most important message here is that monitoring system be properly selected for the situation and that every effort to follow recommended operation within the specified applicability range should be made.

Cost

When selecting a monitoring system or device, the user should be aware that the cost goes far beyond the purchase price of the physical elements of the system. What may seem like a bargain (i.e. staff gage versus automatic water level recorders) may in fact be exorbitantly expensive to the user if 15-minute incremental readings are required during flow conditions. Additionally, calibration/verification exercises could also be extremely expensive, rendering a system undesirable. For example, installing an in-line flowmeter may appear to be expensive. However, if that flowmeter yields a redundant continuous check on the pump rating curve method (both monitoring and calibration requirements are covered), then calibration costs become insignificant.

Flow Range

Many measurement devices have a suggested range of flows for which the manufacturers' will vouch for reliable and accurate measurements. Violating the range could lead to events or part of events that are not well characterized. For example, flumes will simply swamp out if flows exceed rated flows, resulting in unreliable flow measurements. Therefore, trying to manufacture a flume that has proven reliable at relatively low flows for high flow conditions may be completely inappropriate. If a secondary flow measuring device is used, it should have the required accuracy such that it does not appreciably affect the overall system accuracy. For example, installing a flume and reading it with a staff gage once per event results in high costs for marginal accuracy. Finally, when selecting a monitoring system, the user must be sure to select a calibration method of at least the same accuracy.

Adaptability to Site Conditions

Every water delivery site is different and operates normally under unique hydraulic conditions that serve the unique purpose of the site. Also, it must be remembered that all monitoring devices will influence the flow in the system by introducing head, stage, and velocity changes as well as potential diversions of flow. Therefore, imposing an inappropriate monitoring system on a site may appreciable change hydraulic characteristics of the downstream flow, rendering the delivery

system unacceptable. An extreme example of this is to build a diversion of flow through a large open channel flow structure that results in excessive channel scouring and erosion. Ideally, the hydraulic changes introduced by the monitoring system are beneficial, which is typically the case for structures. In all cases, these hydraulic influences need to be carefully considered in the overall system design.

In some irrigation/drainage cases, the same pump/control structure is used to move water in both directions. For these bi-directional flow situations it is unlikely that the same monitoring device will be appropriate for both flow directions. If the system is not properly designed, monitoring for one flow direction could adversely affect monitoring in the other direction. For example, if irrigation and drainage flows occur through the same pipe or structure, an in-line device may be suitable for supply monitoring but completely detrimental to drainage monitoring. Understanding that most meters and hydraulic structures are designed to operate in one direction leads directly to the understanding that, for example, placing in-line meters in a pipe facing different directions will compromise the effective operation of both monitoring systems. Likewise, in the case of open channel structures, weirs and flumes are designed for one-way applications. Placing another structure in the flow stream to monitor flows in opposite directions can completely disrupt the stream hydraulics such that neither system is effective.

There are also cases in the field where pump stations and irrigation supply structures are not well defined and bi-directional flow occurs (pump stations where the primary purpose is to move water laterally under low head and simply allow supply to occur as backflow, intentionally or unintentionally, when supply canals are high enough). These water control stations were not designed for accuracy and selection of flow monitoring and calibration methods becomes a real challenge. The typical approach is to go straight to the pump calibration curves, not acknowledging the fact that what pump rpm suggests is not necessarily the case if significant backflow or leakage is occurring. This situation is common in large axial flow pump stations where pumps could be running for days at constant rpm but the suction head is such that little to no net flow through the pump station is occurring. Also of concern is the situation where sizable backflow occurs through a pump station. One must be ready to concede that open channel flow measurements and calibrations may be most accurate downstream of the water control structure. In short, absolute adherence to theoretical and "accepted" techniques may in fact be unreasonable and less accurate if the flow situation is not fully understood. Adaptability and ingenuity are a must as is providing the supporting data.

Type of Measurement Needed

Measuring and recording instantaneous flows is quite different from flow totalizing and event distribution of flows. Some flow measuring methods like streamgaging, pitot tubes, staff gage readings, etc. do not lend themselves to practical use when continuous values of flow rate are necessary to calculate discharge volume. They are, however, excellent methods for calibrations and as secondary measuring devices/methods and when constant and consistent flow rates can be

demonstrated. These methods can be adapted to take more frequent readings. However, often, starting with a method that satisfies the monitoring requirements is much less costly in the long-term. Here again, a user must analyze the entire process in order to select the best possible and practical monitoring system.

APPLICABLE CHOICES FOR FLOW CONFIGURATIONS

This section summarizes choices for flow measurement configurations that would typically be applicable to South Florida water conveyance systems. This section is only intended as a quick reference guide for the user to identify applicable flow monitoring alternatives for their system. Once identified, the user will need to obtain their own manufacturer specific information to complete the set up in conjunction with the general information provided in the previous sections. Two example cases for the complete setup and operational procedures are provided in Section B of the Guidebook.

Pumps and Head Discharge Curves

Whenever possible, a pump should be looked upon as the least invasive method of monitoring flow if supplied with a rating curve that has been field checked. This method covers all pumps, but can be more problematic for the larger high flow, low head (e.g. axial flow) pumps. Pump rpm and head measurements are needed to be able to go to the rating curves to determine flow. The number of readings needed for an event depends on the variability (more), or consistency (fewer), of the flow. If fewer measurement steps are desired, a user would be advised to install an appropriate in-line flowmeter which can measure and record rates and total volume. In this case, the pump curves and head measurements, in conjunction with the flowmeter, serve as a flow measurement and calibration system. When using pumps and rating curves as the primary flow monitoring devices, the user must be able to demonstrate that calibrations bear out the accuracy of measurement despite the simplifications and assumptions made. For example, in pumped well situations, a drawdown around the well occurs over time as water is removed from the aquifer. In many cases, the drawdown cone stabilizes quickly. Additionally, during long events, the inaccuracies associated with the change in dynamic head may be well within the +/- 10% requirement. While this cannot be assumed, simple calibration checks can be run.

In the case of large axial flow pumps, pump station and inlet conditions are much less uniform than the pumped well cases. Also, leakage around pump stations must be included in the rating curve development. This can be accomplished by calibrating or rating the pump station rather than the pump. Not accounting for changes in intake conditions and leakage can lead to inaccurate water use volume measurements. The reliability of using these pumps as primary measurement devices is highly dependent on the ability to verify the integrity of the pump station itself.

Pipe Flow

Listed below are the types of flow monitoring techniques and their applicability, along with some of the limiting conditions for their use. From the lists, one should also select an appropriate calibration method.

Large pipes (>12 inches)

- Venturi differential head meters
    - best overall accuracy (+/-1% FS)
    - low maintenance and calibration requirements
    - best at flow rates greater than 10 ft^3/s with accuracy drop-off at greater than 150 ft^3/s, and best method for low flow rates
    - measures velocity, requiring calculation for volume
    - no moving parts
    - high initial cost
    - requires a secondary head measuring device
    - best for use in new pressurized installations and where sufficient outlet pipe exists and flows meet minimum and maximum requirements
    - can be retrofit if outlet pipe is in good condition
    - best to use if flow rates are not consistently constant
    - negates need for drawdown monitoring around well
    - best results if automatic recording head gage is used
    - calibration:
        - pump rating curve check
        - pitot tube
        - pitot/static tube
        - dye fluorometry
        - acoustic meters

- Orifice and nozzle meters
    - same as for venturi meters
    - some loss in accuracy (nozzles: +/-1 to 2% FS, orifices: +/-2 to 4% FS

- Doppler and transit-time acoustic velocity meters (ultrasonic)
    - less accurate than the differential meters, but still good if properly used (+/-1 to 5% FS)
    - can be less expensive than differential head meters above, but transit-time meters can cost more
    - handles sediment and debris, but clean water creates problems
    - low or no head loss
    - low maintenance

- velocity and flow rate can be recorded with relative ease
- outlet pipe should be long enough (10 x diameter)
- outlet pipe should be in good condition (little to no rust, physically sound)
- minimal vibrations
- excellent portability for use at more than one pump
- calibration:
  - same as for venturi meters

Small pipes (<12 inches)

- Venturi meters

- Orifice and nozzle meters

- Mechanical meters (propeller, turbine, etc.)
  - accuracy lower than differential head meters (+/-2% FS)
  - low cost
  - works best at flows greater than 10 ft^3/s and less than 150 ft^3/s
  - most log volume only, but some can provide flow rates
  - good for sediment passage
  - larger debris will tend to clog or damage
  - must be properly maintained due to sensitivity of moving parts
  - not as sensitive to pipe condition as head differential methods
  - easy installation
  - fewest worries about suitability, accuracy, operation, etc.
  - calibration:
    - same as for venturi meters
    - can require return to manufacturer for service and calibration

- Magnetic meters
  - good average overall meter
  - relatively expensive
  - less applicability for short pipes
  - higher maintenance
  - calibration:
    - same as for venturi meters

- Acoustic meters (transit-time and Doppler)
  - same as for large pipes
  - calibration:
    - same as for venturi meters
    - often acoustic meter is reserved for calibrations

- Pitot and pitot-static meters
  - accuracy +/-1 to 5% FS
  - best used for instantaneous measurements and calibration
  - not recommended as a continuous monitoring method
  - could have application if flows are demonstrably consistently constant
  - if used for continuous monitoring, water needs to be free of debris to avoid clogging
  - calibration:
    - same as for venturi meters
    - acoustic meters
    - other pitot meters reserved for calibration

Open Channel Flow (includes partially full culverts)

- Long-throated flumes and broad-crested weirs
  - good accuracy (+/-2% FS)
  - flumes are more expensive than weirs
  - wide range of flow rates
  - excellent for lined canals
  - good for unlined canals
  - works well inside culverts
  - measures flow rate and requires volume calculations
  - requires secondary measuring device (head)
  - good for sediment passage, but watch for build-up
  - excellent for debris passage but watch for clogging
  - long-lasting and low maintenance
  - requires good design and installation
  - calibration:
    - electromagnetic flowmeters
    - acoustic meters
    - mechanical open channel flowmeters
    - dye flurometry
    - open channel pitot tubes
    - require velocity-area/streamgaging exercises for volume checks

- Short-throated flumes and sharp-crested weirs
  - good accuracy (+/-5% FS)
  - short-throated flumes are more expensive
  - sharp-crested weirs are better for low flows
  - short-throated flumes are better for debris and sediment passage
  - watch floating macrophyte build-up
  - proper construction is complicated

- calibration:
    - same as for long-throated flumes and broad-crested weirs

- Flow control structure rating (includes siphons, submerged culverts, risers and boards, etc.)
    - well within accuracy requirements if rating curves are properly derived (+/-5%)
    - takes advantage of existing structures
    - requires diligent maintenance of structures
    - structures must be treated as measurement devices and replaced when damaged
    - rating curves may be estimated for standard geometries
    - flashboard risers with known board settings can use known rating curves
    - variable board settings will require additional work
    - nonstandard geometries require development of a rating curve
    - rating curves must be developed over the span of expected heads and flows
    - leakage around structures must be considered during rating curve development
    - maintenance to clear debris and sediment is necessary if clogging occurs, but typically this is not a problem
    - inexpensive and practical
    - requires secondary head monitoring device
    - accuracy is lost if physical damage/change occurs
    - requires most frequent recalibration/verification
    - possibly the most frequently used method since proper rating yields good results
    - the cost of rating curve development and maintenance may exceed cost of flume
    - calibration/verification:
        - same as for long-throated flumes and broad-crested weirs

- Area-Velocity/Streamgaging (no flow monitoring/control structure)
    - good for point-in-time measurements, limited use for continuous monitoring
    - good when no hydraulic structure is present
    - may be developed such that a single velocity measurement point is sufficient
    - must monitor at same physical point
    - all flow must be accounted for
    - loses reliability in leaky systems or complicated flow geometries
    - low equipment cost, but can have high labor cost
    - must be able to verify constant and consistent flows during measurement
    - best suited for calibration/verification exercises
    - current meter selection required
    - good choice for continuous monitoring if flow is consistently constant
    - calibration/verification:
        - requires recalibration of the stream section

The above methods are listed in order of their accuracy and applicability to the given configuration. However, all methods fall within the required +/-10% accuracy range if due diligence is taken during installation, monitoring and calibration. Likewise, any of the methods may exceed acceptable accuracy tolerances if misused or poorly installed. Hence, recordkeeping becomes an important part of the monitoring process. A user must select the monitoring method that is best suited to the physical configuration of the water withdrawal station/structure. While broad-throated flumes and broad-crested weirs may be the ideal, retrofitting them to an existing system simply may not make sense for the accuracy gained and expense incurred.

Calibration/verification is an important part of the monitoring process and must be figured in as part of the expense of a system. For example, while installation of a broad-crested flume may seem exorbitantly expensive initially, the cost of calibrating and verifying a rating curve for an existing culvert on a much more frequent basis may actually cost more. A monitoring program must account for this trade-off.

Finally, reiterating, every water conveyance structure/geometry is different and must be treated individually. It must be understood that there are some situations where selecting a less accurate method is the only option. Additionally, it should be understood that a less accurate meter or structure can yield accuracies that are better than the more expensive and accurate devices depending on the relative levels of care and effort that are put into the monitoring program. There are some situations where ingenuity and creativity will be required and textbook procedures will not be applicable. For example, all streamgaging or velocity/area methods call for upstream monitoring. In the case of multiple inflows just upstream of the control structure, calibrating upstream may extremely difficult. Hence, taking measurements downstream will have to be necessary and is perfectly acceptable as long as distances from the structure are short and all water is accounted for. If significant seepage occurs, calibrations will be in error unless seepage is accounted for. Additionally, if farm canal configurations are such that lateral ditches preclude finding a suitably long section of main, calibrations may occur as long as provisions for accounting for flow in the laterals are made in a timely fashion. In some cases, locating a point of near-average velocity in a channel will need to be done to enable the velocity-area/streamgaging method to be used for continuous monitoring. This point of average velocity should be demonstrable repeatedly during the rating of the cross-section, yielding a suitably accurate monitoring method as long as it is verifiable using dye fluorometry or portable structures. With all of the methods discussed falling well within the accuracy tolerances, some deviations from absolutes are acceptable.

Any other method or instrument may be used after acceptance by the SFWMD. Many new velocity or head measuring devices are being developed. If use is desired, the ability to show repeatable and accurate results is the burden of the user.

Secondary Measuring Devices

Discharge through a primary device (pump, culvert, weir, flume, etc.) is calculated as a function of water level(s) or head(s). A detailed description of the various available devices was presented in an earlier section and will not be repeated here. However, as a quick reference guide, a brief discussion of applicability and effectiveness of head measurement devices is presented below.

- Pressure transducers
    - most accuracy potential
    - offers continuous recording capabilities
    - relatively expensive
    - no moving parts but must generally be replaced when malfunctions
    - requires a power source and datalogger

- Mechanical float-pulley recorder
    - accuracy depends on float size, chart paper, gears
    - epitomized by the Stevens Type F recorder
    - charts cause a loss of accuracy as does the buoyancy of the float
    - float tape or beaded line will malfunction under rapid vertical movement of water
    - high maintenance to achieve desired resolution
    - reading chart values can be subjective
    - accepted as a reliable and accurate instrument for large flow volume applications
    - charts can be eliminated with potentiometric devices producing electronic signals

- Acoustic devices
    - range from submerged type to those that "look down" on the water surface
    - acts much like photographic autofocus sensors
    - accuracy is generally good

- Resistive strips
    - accuracy is generally good
    - requires a power source and datalogger
    - relatively expensive

- Staff gages
    - accuracy is poor (smallest division is 0.01 ft but difficult to read)
    - point-in-time measurements only
    - fluctuations in water surface cannot easily be mathematically smoothed
    - good for decision-making
    - good in situations where flow rates are very consistent enabling very few readings

The proper selection of a head measuring device depends on the intent of its use. For example, staff gages are an excellent choice if only occasional readings are necessary to achieve a good characterization of flow. However, if flows are not demonstrably consistent to enable one or two readings to be taken to characterize an event, one must select a different method. The cost of the monitoring instrumentation jumps immediately if staff gages are insufficient. However, a user is reminded that factoring labor costs to achieve demonstrable accuracy may immediately suggest that an automatic recording float-pulley or pressure transducer system be installed.

Maintenance and calibration of these recording devices are generally low, but routine verification of function is required.

FINAL WORD ON MONITORING SYSTEM SELECTION

All devices discussed above are suitable for achieving the desired accuracy required by the regulatory program. All instruments and structures will yield sufficient accuracy as long as they are installed and used according to manufacturers' specifications and are appropriately applied to the field situation. The methods discussed, however, are not meant to be an exhaustive and exclusive listing. They are, however, the most well known and accepted methods available that provide accurate flow and volume measurements.

Structures and methods may be adapted for different circumstances. For example, a farm turnout from a main SFWMD ditch or canal may not have a structure currently in place that is suitable for flow monitoring. A suitable upstream reach to install a device is simply unavailable. Hence, moving upstream of the device onto the farm will provide the best available place for area-velocity/streamgaging activities. As long as the apparent total volume of water brought on to the farm is accounted for, the monitoring position will be adequate. If a secondary farm ditch precludes measurement in the main farm canal/ditch due to proximity of the withdrawal point, setting up a monitoring station in both ditches will in fact be a good option. Further, placing large culverts in a ditch just to better define the channel geometry is a viable option to flumes and weirs. While potential accuracy will not be as good, given appropriate calibrations and secondary head measurements, the simple culvert will provide volume estimates well within the +/-10% criterion.

Common sense must also prevail in mating primary and secondary monitoring structures/equipment. For example, one would not install a flume and a staff gage to be read once during an event. Striving for accuracy by incurring the expense of installing a flume will usually be totally negated by using a less than ideal secondary device. Yet, from an expense standpoint, it may make sense to spend the money on an accurate primary device and cut costs on a secondary device/method if one can still remain within the accuracy requirements. The bottom line is that primary and secondary devices can be mixed and matched to remain within a

user's comfort zone while achieving sufficiently accurate results. The best primary structure simply does not mandate the best secondary device.

Finally, selection of the calibration/verification method must be carried out and used appropriately. With all methods' accuracies tightly clustered and rarely exceeding +/-2 to 5% (laboratory rating) and +/-5 to 10% in field use, calibration methods should be recognized as having the same vulnerabilities when used in nonuniform field situations. Hence, simply selecting a device/method that performs better in a laboratory situation may not lead to the satisfactory conclusion that it will outdo the accuracy of another method. In the case where a structure is being calibrated to derive rating curves, the best possible method should be used (this is what occurs in laboratory device calibrations). However, once calibrated and in use, one should look at calibrations as verification exercises and use due diligence when deciding when a rating curve needs to be replaced. Water measurement in large water bodies and nonuniform open channel field conditions is not an exact science and will never result in an exact volume determination. It is an exercise in achieving the best estimates possible. Measurements in pipe flow under pressure are quite a bit more exact and much less dependent on field nonuniformities.

SECTION B

Flow Monitoring Modules for Specific Cases

Section B

Teaching Modules For Flow Accounting And Verification

Objectives of today's meeting

- Explain the District's water use accounting and calibration requirements

- Provide training for calibration & monitoring program

- Answer questions/clarify confusion associated with the program

Definition of Terms

- <u>Water Use Accounting</u>: measuring and reporting water use per limiting conditions of permit

- <u>Calibration</u>: Measurement of actual flow for the purpose of determining the accuracy of the permitted water use accounting method

  - Initial calibration required as a condition of permit issuance

  - Re-Calibration every 5 years or if system modifications affect validity of existing calibration

Why is the District Requiring the Calibrations and Reporting?

- **The SFWMD is charged by the Florida Legislature with managing water use in South Florida**

- **One important task in this charge is planning to meet future water demand**

Why are reliable water use accounting methods needed?

Assess impacts to water resources and existing legal uses

- Assess effectiveness of water conservation

- Ensure use is consistent with conditions of permit

Comparison with other district's programs

- **SJRWMD requirements**
  - Meters- 95% accuracy: alternative accounting method- 90% accuracy
  - Calibration every 3 years
  - Monthly readings reported semi-annually
- **SWFWMD requirements**
  - Meters and alternative methods 95%
  - Calibration every 2 years
  - Monthly readings reported monthly

What is required under this program

- **Monthly total pumpage for each permitted withdrawal facility reported quarterly**

- **Accounting method specified in permitting**

- **Measurement accurate to ± 10% of actual flow (90% accuracy)**

- **Withdrawal facilities to be calibrated every five years**

What is required under this program

- **Accounting <u>not required</u> for:**
  - **Uses less than 3,000,000 million gallons per month (<15,000,000 million gallons per month for South Dade Ag Basin)**
  - **Internal pumps for routing water that are not listed in the permit**
  - **Secondary users served by Improvement District permit**
  - **Areas in the EAA served by District pumps**

What is being done to minimize the costs of water use accounting

- **Provides flexibility in the method of accounting**
    - **User's choice; accurate and reliable**

- **Calibration frequency reduced from every other year to every five years**

- **"Open market" approach to calibration services**
    - **Calibration vendor list**
    - **Training open to everyone**

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Before Getting Started

There are a few truisms that should be kept in mind when selecting and using a flow monitoring or verification method.

Permit Requirements Must be Adhered to

- **Water use > 3 Million gallons/month (> 15 million gallons/month for South Dade Ag Basin)**

- **Quarterly reporting of monthly flows**

- **Flow monitoring accuracy of ± 10% error**

- **Periodic verification of monitoring accuracy**

Choose the Most Appropriate Flow Measurement Method

- The method must be suitable for the specific facility and flow conditions.

- The "most accurate" method may not always yield the best results because of prevailing conditions and operator experience.

- "Textbook methods" are based on ideal conditions which rarely, if ever, occur in the field.

- Familiarize yourself with the detailed discussions in Sections A and C.

Have the Appropriate Training

- The proper application of a flow monitoring method is essential.

- A good method with poor application will yield poor results.

- The most technical or complicated method may be the most expensive and least accurate because of inadequate operator training.

Document Conditions During Monitoring

- Field conditions are variable and can change on a daily basis.

- Detailed records of weather and other field conditions at the time of measurement will often help to justify the use of the method and explain possible errors.

- Records will also help to show that a proper method was selected and that the operator was properly diligent.

Submit the Appropriate Forms

- Use of SFWMD approved forms is strongly advised.

- Using the forms shows due diligence and provides the SFWMD with uniform reporting for ease of information handling and feedback.

- Flow measurement can be complicated. Using the appropriate forms will ensure that all data and measurement steps were correct and that no more work than necessary was done to produce accurate results.

- Forms must be filled out properly with all requested information.

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Perform Flow Verifications During the Dry Season

- Water demand and use is critical during the dry season.

- Verifying flows when prevailing conditions in the area are in the drainage mode may lead to erroneous data.

- The dry season is defined as January 1 through June 1 during a normal year.

- Dry season flow verifications should provide acceptable water use accounting accuracy when averaged over a 12-month period. However, there will be years with extreme conditions which may require additional verification efforts.

Other Considerations

- Many of the methods discussed herein may be used for both flow measurement and reporting, as well as for verification/calibration.

- It is recognized that method modifications may be necessary to adequately measure water flow at a given location.

- It is recognized that there are many appropriate simplifications or modifications of standard equations.

- It is recognized that there are some water use structures that are not conducive to the use of any measurement method in this handbook.

- Modifications to account for the above conditions will be considered by the SFWMD. It is strongly advised that a Florida registered professional engineer be consulted prior to implementing any modifications.

General Information Reporting Required for All Methods

- **Permit Number/Application Number**
- **Project Name**
- **Site Contact Information/Phone Number**
- **SFWMD Facility ID/GPS coordinates**
- **Withdrawal Source Type (well, lake, canal name, etc.)**
- **Withdrawal Type (pumped, gravity, artesian, other)**
- **Facility Water Use Accounting Method**
- **Facility Flow Verification Method**

Two General Flow Categories

- **Flow measurement requires determining what volume of water passes through a known area during a given amount of time (Q = V x A).**

- **Flow in closed conduits**
  - **Flow not exposed to atmosphere**
  - **Ex. pipes, submerged culverts, pumps**

- **Flow in open channels**
  - **All flow occurs with surface exposed to atmosphere**
  - **Ex. streams, channels, weirs, partially filled culverts, control structures, flumes**

California Method

- **Required Conditions:**
  - Level (horizontal) discharge pipe, with length 6 or more times the pipe diameter to ensure that flow is not disturbed by joints, bends, pumps, etc.
  - Discharge pipe must not be added to, or subtracted from (pipe length or fittings), after calibration
  - End of pipe must be straight cut
  - Pipe must not be flowing full
  - Must have access to discharge end of pipe for measurement

California Method Schematic for Applicability and Measurements

Measurements to be taken

Level Horizontal Discharge Pipe

D

6D or greater

a
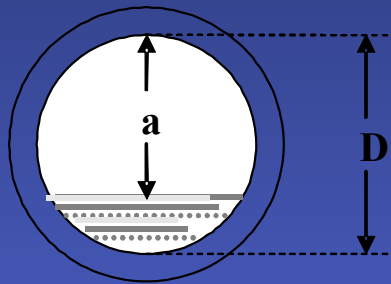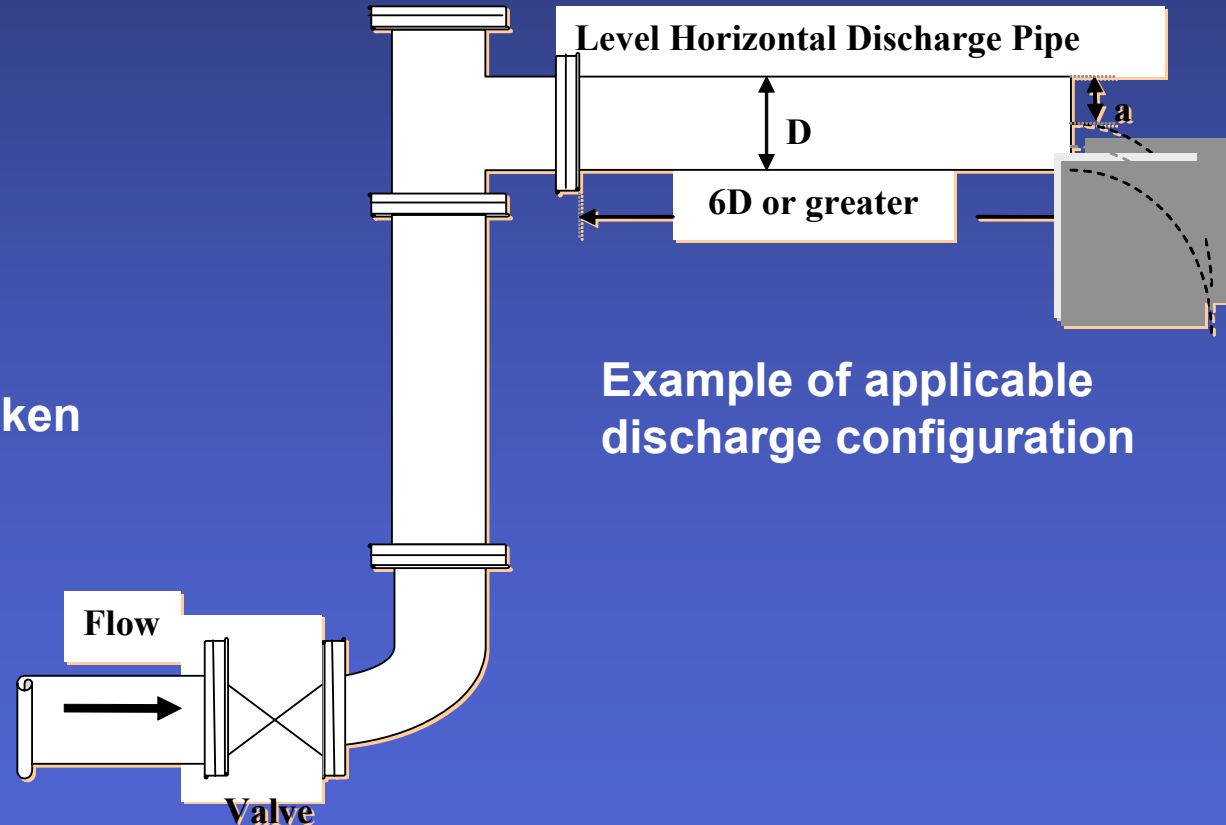
Example of applicable discharge configuration

Flow

Valve

Test Procedure

- Use a carpenter's level to ensure that the discharge pipe is level (horizontal) and its opening is square (vertical and horizontal)

- Measure the inside pipe diameter unless it is standard and known

- Allow flow in the pipe to occur for at least 15 minutes to obtain stable and consistent flow conditions (gap space should not be fluctuating rapidly)

- Measure the height of the gap between the top of the inside of the pipe and the top of the water stream as it exits the pipe

- Repeat the gap measurement 3 times on at least 5-minute intervals

- Calculate flow

Measurement Example and Calculations - 1

Preliminary data:

Length of horizontal discharge pipe, L: <u>4 ft. (48 in.)</u>
Inside diameter of horizontal discharge pipe, D: <u>4 in.</u>
Is length greater than 6 times inside diameter (L > 6 x D)?:
     48 in. > 6 x 4 in.?

     48 in. > 24 in.?:   <u>Answer must be yes</u>
Is pipe level (horizontal)?:   <u>Answer must be yes</u>
Is discharge opening square?: <u>Answer must be yes</u>

Proceed with flow data collection and calculations only if all 3 answers are "yes". If any answer is "no", permanently amend the configuration to satisfy the requirements or select another flow measurement method.

Measurement Example and Calculations - 2

	Three measurements, in.			Average
Gap height, a:	2.5	2.0	1.5	2.0 in

Flow (Q) in cubic feet per second (cfs, ft³/s):

$Q = 8.69 \times (1 - a/D)^{1.88} \times D^{2.48}$, a and D in ft.

a = 2 in/12 = 0.165 ft.

D = 4 in/12 = 0.33 ft.

$Q = 8.69 \times (1 - 0.165/0.33)^{1.88} \times 0.33^{2.48} = 0.15$ cfs

Q in gpm = 0.15 cfs x 448.8 = 67.3 gpm

Doppler and Other External Flow Meters

- **Required Conditions:**

  - **Acceptable length of straight pipe, generally at least 6 to 10 pipe diameters away from any bends or fittings that may disturb the flow path**

  - **Pipe must be exposed so as to be accessible**

  - **Pipe must flow full at point of measurement (pressurized systems operating properly will always have full flow conditions)**

  - **Pipe vibrations must be minimal**

Doppler and External Flow Meter Applicability Examples

Examples of applicable discharge and monitoring configurations

Flow

Reflective Particle

Averaged Velocity Area

Transmitted Signal

Reflected Signal

Doppler Transducer
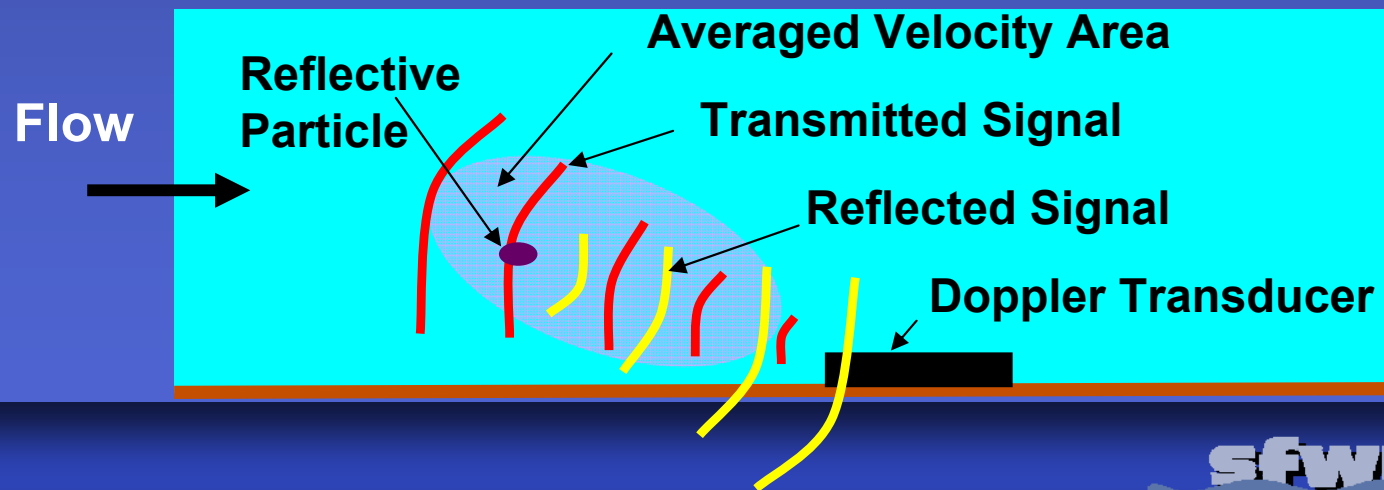
Test Procedure

- **Meters will yield direct readings of velocity**

- **Allow flow in the pipe to occur for at least 15 minutes prior to measurement to obtain stable and consistent flow conditions**

- **Determine the inside area of the pipe from design specifications or direct measurement**

- **Take at least 5 discrete velocity readings on at least 5 minute intervals**

- **Average the discrete velocity measurements**

- **Calculate flow**

Measurement Example and Calculations - 1

Preliminary data:

Length of horizontal discharge pipe, L: <u>15 ft (180 in)</u>

Inside diameter of horizontal discharge pipe, D: <u>24 in</u>

Is length greater than 6 times inside diameter (L > 6 x D)?:

      180 in > 6 x 24 in?

      180 in > 144 in?:   <u>Answer must be yes</u>

Is there a suitable length of pipe exposed for attaching measurement device?:   <u>Answer must be yes</u>

Proceed with flow data collection and calculations only if answers are "yes". If any answer is "no", permanently amend the configuration to satisfy the requirements or select another flow measurement method.

Measurement Example and Calculations - 2

Five measurements, velocity (V) in ft/s   **Average V**
8.56   8.55   8.57   8.57   8.55   8.56 ft/s

Cross-sectional Area of Pipe, A (ft^2):
Pipe inside diameter = 24 in = 2 ft
A = (π x D^2)/4 = (π x 2^2)/4 = <u>3.14 ft^2</u>

Flow (Q) in cubic feet per second (cfs, ft^3/s):

Q = V x A
Q = 8.56 ft/s x 3.14 ft^2 = 26.88 ft^3/s
Q in gpm = 26.88 ft^3/s x 448.8 gpm/ft^3/s = 12,063 gpm

Dye Fluorometry or Chemical Gauging Method

- **This method requires specialized equipment and expertise and should be conducted or supervised by a Florida licensed professional engineer (P.E.)**

- **Contact the SFWMD or the Florida Section of the American Society of Agricultural and Biological Engineers for a listing of professionals available**

- **See Section A for a discussion about the method**

Dye Tracer or Color Method

- **Required Conditions:**
  - **Applicable to either open channels or pipes as long as the cross-sectional flow area is known or measurable (no major channel geometry changes)**
  - **Flow must be steady (no changes in flow depth for open channels) and constant**
  - **Access to a point for injecting dye must be available**
  - **Must be able to see discharge point and observe color change**
  - **Dye must be injected perpendicular to flow**
  - **Dye should be injected near the area of theoretical mean velocity (0.6 of the total depth of flow for open channels and at 15% to 29% of the diameter for pipes, see Section A)**
  - **Injector should have positive on/off control at tip to avoid leakage**

Theoretical Location of Average Velocity for Dye Injection

Pipes
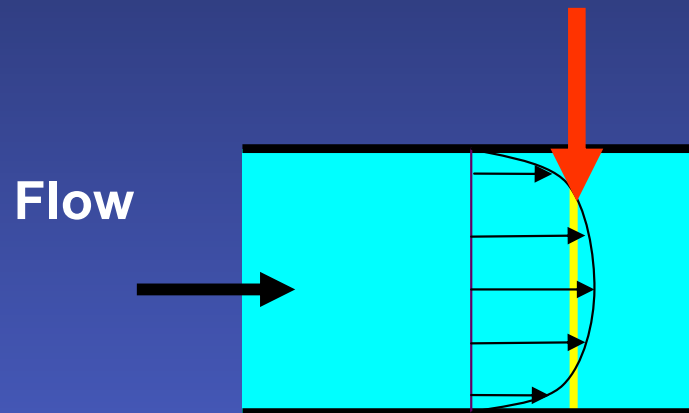
Flow

Inject dye at a point between 15% and 29% of the pipe inside diameter in from the pipe wall, perpendicular to flow

Open Channels
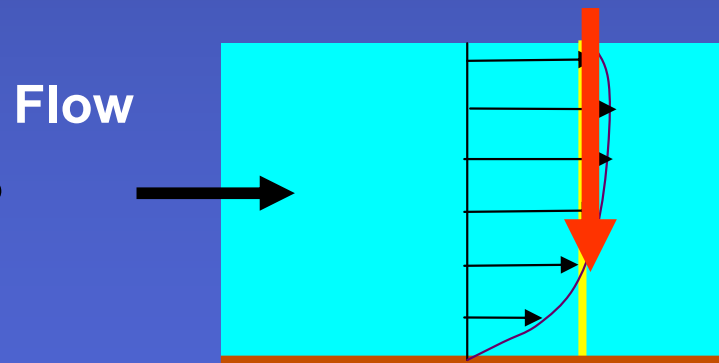
Flow

Inject dye at a point 0.6 of the channel depth down from the water surface, perpendicular to the flow path

Test Procedure – Canal or Pipe with Uniform Geometry

- Determine the cross-sectional area of flow, A (ft²)

- Measure the distance between the injection point and downstream observation point, D (ft)

- Simultaneously and instantaneously trigger the injection device and a stop watch

- Stop the stopwatch and record the elapsed time when a color change is observed at the observation point, T (s)

- Repeat the process a minimum of 2 more times

- Average the time measurements

- Calculate flow

Test Procedure – Canal or Pipe with Variable Geometry

- Determine the cross-sectional area of flow, A (ft^2), for each uniform segment of the pipe or channel (A$_1$, A$_2$, A$_3$, etc.)

- Measure the length of each uniform segment (ft) (L$_1$, L$_2$, L$_3$, etc.)

- Multiply each segment length by its corresponding area to obtain segment volumes.

- Sum the segment volumes

- Measure the distance between the injection point and downstream observation points, D (ft)

- Simultaneously and instantaneously trigger the injection device and a stop watch

- Stop the stopwatch and record the elapsed time when a color change is observed at the observation point, T (s)

- Repeat the process a minimum of 2 more times

- Average the time measurements

- Calculate flow

Measurement Example and Calculations for Uniform Section - 1

Uniform channel cross-sectional area, A (assumed trapezoidal):

Bottom width, a: 5 ft
Width at water surface, b: 15 ft
Water depth at center of channel, c: 2.5 ft
Distance between injection and observation points, D: 85 ft
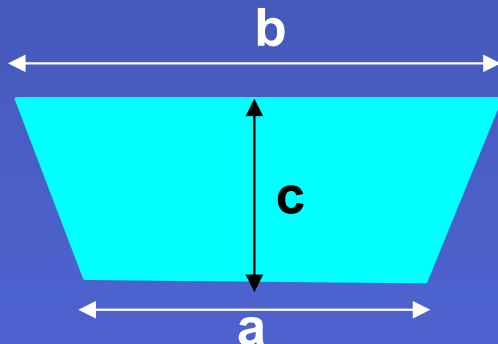
Channel cross-sectional area:

A = (a + b) x c/2
A = (5 + 15) x 2.5/2
A = 20 x 1.25
A = 25 ft^2

Measurement Example and Calculations for Uniform Section - 2

Stopwatch readings for dye to move distance D (85 ft), time (T):

Test 1	Test 2	Test 3	Average T, s
85	84	86	<u>85 s</u>

Average flow velocity through test section:

V = D/T

V = 85/85 = 1 ft/s

Average flow in channel, Q (cfs):

Q = V x A

Q = 25 x 1 = 25 cfs

Average flow in channel, Q (gpm):

Q = 25 cfs x 448.8 gpm/cfs = 11,220 gpm

Electromagnetic Insertion and External Meters

- **Required Conditions:**
  - Applicable to open channel or pipe flow (full or partial) where cross-sectional area of flow can be determined
  - Flow must be steady (unchanging water surface level) and constant
  - Must have access to measurement point
  - Measurement point for pipes should be 6 to 10 pipe diameters away from and bends, pumps, joints, meters, etc. that cause flow disturbances
  - Probe must be perpendicular to flow direction
  - Flexing and vibration of probe assembly should not occur
  - Meters must be calibrated by the factory or other qualified personnel according to manufacturer's specifications prior to their use.

Test Procedure – Full Pipe Flow

- Determine pipe inside diameter, D (ft)
- Calculate cross-sectional area of flow, A (ft^2)
- Install meter probe according to manufacturer's recommendations
- Observe velocity readings over a 10 to 15 minute period to ensure stable flow conditions
- If velocity readings fluctuate by more than 10%, continue observation until flow stabilizes or determine and resolve the cause of fluctuations
- Record 10 velocity (ft/s) readings over a 5-minute period
- Average the measurements to obtain an average velocity
- Calculate flow, Q (cfs)

Measurement Example and Calculations for Full Pipe Flow - 1

Pipe Inside Diameter: 36 in = 3 ft

Length of pipe section = 18 ft

Length/Diameter > 6?: 18/3 = 6, so acceptable

Electromagnetic meter velocity readings, V (ft/s):

V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9

Average flow velocity through test section:

$$V = (V_1 + V_2 + V_3 + \ldots + V_{10})/10$$

$$V = 9.45 \text{ ft/s}$$

Measurement Example and Calculations for Full Pipe Flow - 2

Cross-sectional area of pipe, A (ft^2):
   $A = (\pi \times D^2)/4$; where $\pi \sim 3.14$
   $A = (3.14 \times 3^2)/4 = 7.07$ ft^2

Flow in pipe, Q (cfs):
   $Q = V \times A$
   $Q = 9.45 \times 7.07 = 66.81$ cfs

Flow in pipe, Q (gpm):
   $Q = 66.81$ cfs $\times 448.8$ gpm/cfs $= 29{,}985$ gpm

Test Procedure – Partially Full Pipe Flow

- Determine pipe inside diameter, D (ft)

- Determine depth of flow in pipe, d (ft)

- Calculate d/D and locate multiplication factor from table in Section C, Appendix C (standard table following)

- Calculate cross-sectional area of flow as D^2 x multiplication factor.

- Measure velocity according to procedures for full pipe flow

- Calculate flow, Q (cfs)

Measurement Example and Calculations for Partial Pipe Flow - 1

Pipe Inside Diameter: 36 in = 3 ft
Length of pipe section = 18 ft
Length/Diameter > 6?: 18/3 = 6, so acceptable

Electromagnetic meter velocity readings, V (ft/s):

V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9

Average flow velocity through test section:

$V = (V1 + V2 + V3 + \ldots + V10)/10$

$V = 9.45$ ft/s

Measurement Example and Calculations for Partial Pipe Flow - 2

Cross-sectional area of flow in pipe, A (ft^2):

D = 36 in = 3 ft

d = 13.68 in = 1.14 ft

d/D = 13.68/36 = 0.38

Multiplication factor = 0.2739 (from table)

$A = 0.2739 \times D^2$

$A = 0.2739 \times 3^2$

$A = 2.47$ ft^2
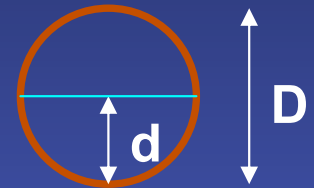
Flow in pipe, Q (cfs):

$Q = V \times A$

$Q = 9.45 \times 2.47 = 23.3$ cfs

Flow in pipe, Q (gpm):

$Q = 23.3$ cfs $\times 448.8$ gpm/cfs = 10,455 gpm

Cross-Sectional Area of Flow for Partially Full Pipes

(Section C, Appendix C)

$\frac{d}{D}$	Multiplication Factor = $\frac{WetArea}{D^2}$	$\frac{d}{D}$	Multiplication Factor = $\frac{WetArea}{D^2}$	$\frac{d}{D}$	Multiplication Factor = $\frac{WetArea}{D^2}$	$\frac{d}{D}$	Multiplication Factor = $\frac{WetArea}{D^2}$
0.01	0.0013	0.26	0.1623	0.51	0.4027	0.76	0.6405
0.02	0.0037	0.27	0.1711	0.52	0.4127	0.77	0.6489
0.03	0.0069	0.28	0.1800	0.53	0.4227	0.78	0.6573
0.04	0.0105	0.29	0.1890	0.54	0.4327	0.79	0.6655
0.05	0.0147	0.3	0.1982	0.55	0.4426	0.8	0.6736
0.06	0.0192	0.31	0.2074	0.56	0.4526	0.81	0.6815
0.07	0.0242	0.32	0.2167	0.57	0.4625	0.82	0.6893
0.08	0.0294	0.33	0.2260	0.58	0.4724	0.83	0.6969
0.09	0.0350	0.34	0.2355	0.59	0.4822	0.84	0.7043
0.1	0.0409	0.35	0.2450	0.6	0.4920	0.85	0.7115
0.11	0.0470	0.36	0.2546	0.61	0.5018	0.86	0.7186
0.12	0.0534	0.37	0.2642	0.62	0.5115	0.87	0.7254
0.13	0.0600	**0.38**	**0.2739**	0.63	0.5212	0.88	0.7320
0.14	0.0668	0.39	0.2836	0.64	0.5308	0.89	0.7384
0.15	0.0739	0.4	0.2934	0.65	0.5404	0.9	0.7445
0.16	0.0811	0.41	0.3032	0.66	0.5499	0.91	0.7504
0.17	0.0885	0.42	0.3130	0.67	0.5594	0.92	0.7560
0.18	0.0961	0.43	0.3229	0.68	0.5687	0.93	0.7612
0.19	0.1039	0.44	0.3328	0.69	0.5780	0.94	0.7662
0.2	0.1118	0.45	0.3428	0.7	0.5872	0.95	0.7707
0.21	0.1199	0.46	0.3527	0.71	0.5964	0.96	0.7749
0.22	0.1281	0.47	0.3627	0.72	0.6054	0.97	0.7785
0.23	0.1365	0.48	0.3727	0.73	0.6143	0.98	0.7816
0.24	0.1449	0.49	0.3827	0.74	0.6231	0.99	0.7841
0.25	0.1535	0.5	0.3927	0.75	0.6319	1	0.7850

Test Procedure – Open Channel Flow

- **Determine cross-sectional area of flow in test section using procedures in dye method for trapezoidal channels**

- **For non-trapezoidal channel area measurement, use vertical (below) method from stream gauging techniques**

- **Follow velocity measurement procedures for partially full pipe flow**

x_i

d_i

Take depth reading at center of each vertical segment

Area $= \Sigma(x_i \times d_i)$

Canal bottom
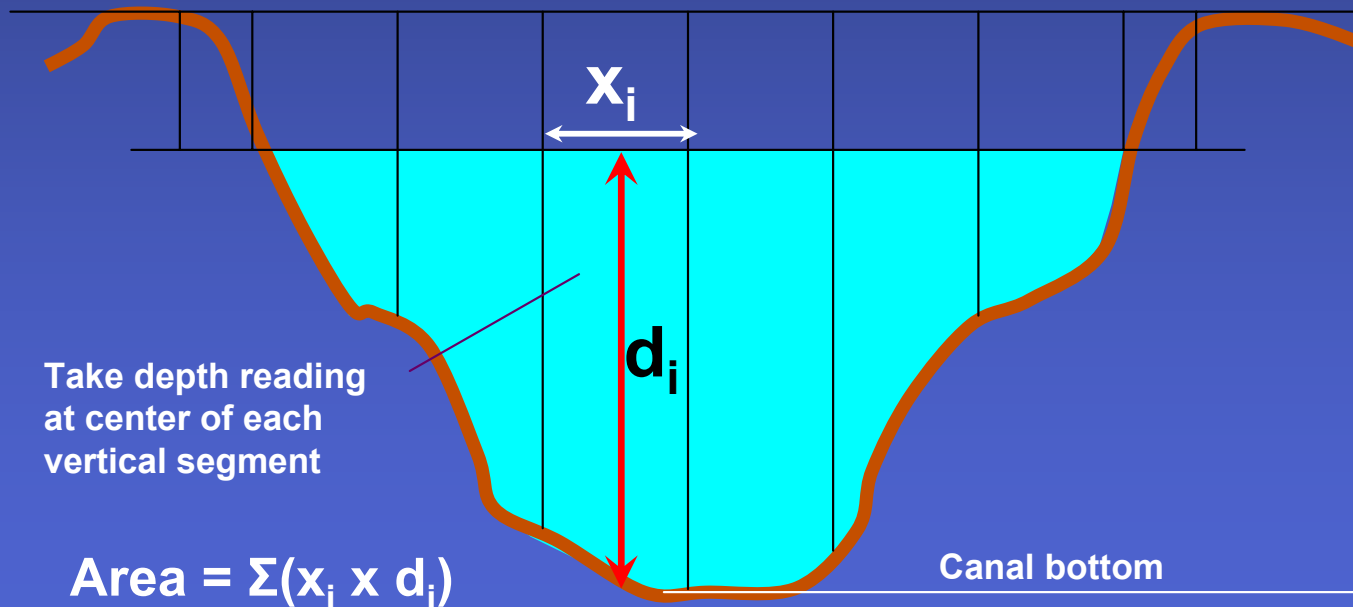
1. Divide the channel into equal sections of known width (x_i).
2. Measure the depth of water in the middle of each segment (d_i).
3. Multiply x_i and d_i to get area of segment.
4. Add areas of all segments.

Measurement Example and Calculations for Canal/Ditch Flow - 1

Uniform channel cross-sectional area, A (assumed trapezoidal):

Bottom width, a: <u>5 ft</u>
Width at water surface, b: <u>15 ft</u>
Water depth at center of channel, c: <u>2.5 ft</u>

Channel cross-sectional area:

A = (a + b) x c/2
A = (5 + 15) x 2.5/2
A = 20 x 1.25
<u>A = 25 ft^2</u>
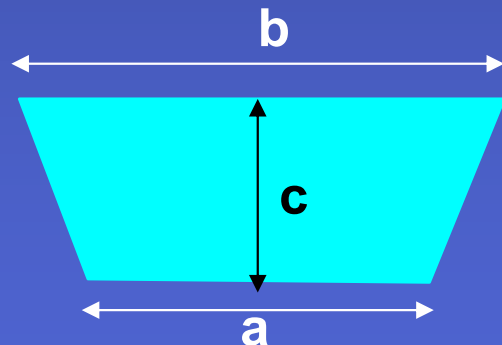
Measurement Example and Calculations for Canal/Ditch Flow - 2

Electromagnetic meter velocity readings, V (ft/s):

V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4

Average flow velocity (V) through test section:

V = (V1 + V2 + V3 + … + V10)/10

<u>V = 0.95 ft/s</u>

Average flow (Q) in open channel:

Q = V x A

Q = 0.95 ft/s x 25 ft^2

Q = 23.75 cfs

Average flow in gpm: 23.75 cfs x 448.8 gpm/cfs = 10,659 gpm

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Float Velocity Method

- **Required Conditions:**
  - Least desirable method, but can yield good results if done carefully
  - Must be conducted in a channel section with no turnouts or inlets between the pump and the test section
  - There must be a straight section of channel with no turbulence that allows the floats to travel for at least 20 seconds
  - The channel section must be uniform and have no vegetation or debris that could alter float speed and direction
  - Water depth must be at least 1 foot
  - Access to float release points must be available
  - Measurements must not be run on windy days, no matter what the wind direction

Test Procedure

- Mark float travel start and end points along the channel

- Use similar floats (material, size and weight)

- Select the number of floats to use

- Place the floats evenly across the width of the channel at least 5 feet apart and at least 3 feet upstream of the float travel start point

- Record the time it takes each float to travel from the start point to end points

- Repeat the measurements at least 2 more times

- Measure the channel cross-sectional area in the test section

- Greater accuracy can be gained by using stream gauging techniques for determining cross-sectional area and flow velocity (see Electromagnetic Meter example)

Measurement Example and Calculations for Float Velocity Method - 1

Uniform channel cross-sectional area, A (assumed trapezoidal):

Bottom width, a: 5 ft
Width at water surface, b: 15 ft
Water depth at center of channel, c: 2.5 ft
Distance of channel between start and end points, D: 100 ft
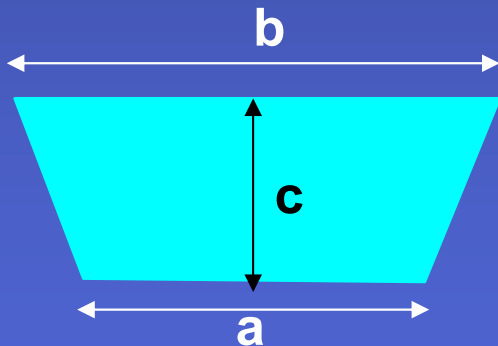
b

c

a

Channel cross-sectional area:

A = (a + b) x c/2
A = (5 + 15) x 2.5/2
A = 20 x 1.25
A = 25 ft^2

Measurement Example and Calculations for Float Velocity Method - 2

Recommended Number of Floats:

Ditch width at water surface (ft)	Number of Floats
0 – 10	1
10 – 15	2
15 – 20	3
20 – 25	4

Water surface width = 15 ft, therefore use 2 floats

Test 1: Float 1 travel time, T = 82 s, Float 2 time, T = 88 s, T_{ave} = 85 s
Test 2: Float 1 travel time, T = 80 s, Float 2 time, T = 88 s, T_{ave} = 84 s
Test 3: Float 1 travel time, T = 85 s, Float 2 time, T = 87 s, T_{ave} = 86 s
All tests T_{ave} = (85 + 84 + 86)/3 = 85 s

Measurement Example and Calculations for Float Velocity Method - 3

Average flow velocity through test section:

$V = (0.85 \times D, ft)/T, s$

$V = (0.85 \times 100 \ ft)/85 \ s$

$\underline{V = 1.0 \ ft/s}$

Average flow (Q) in open channel:

$Q = V \times A$

$Q = 1.0 \ ft/s \times 25 \ ft^2$

$Q = 25 \ cfs$

Average flow in gpm: 25 cfs x 448.8 gpm/cfs = 11,220 gpm

Flow Probe Meter Method

- **Required Conditions:**
  - **Applicable to full or partially full pipe flow through structures such as culverts or surface water discharge pipes**
  - **Flow stream must not contain excessive debris**
  - **Must have access to end of discharge pipe**
  - **Flow direction changes and eddies must not be in the vicinity of the measuring point**
  - **Meter must be kept calibrated according to manufacturer's specifications**

Test Procedure

- Determine the inside diameter of the pipe/conduit in the same units of measure as the flow probe reads (i.e. diameter in feet if flow probe measures in ft/s)

- Let flow occur long enough to ensure normal and stable conditions before measurements are made

- If full pipe flow is occurring, position the flow probe at the end of the conduit, or slightly inside, at a distance approximately 29% of the diameter in from the conduit wall (recommended from the bottom up and from one side in towards the middle)

- If the pipe is flowing partially full, measurements should be taken at the average velocity point for open channel flow (approximately 0.6 times the depth of flowing water down from the water surface in the center of the conduit)

- Take readings at least every minute for 5 minutes to obtain a good average flow velocity

Measurement Example and Calculations for Full Pipe Flow - 1

Pipe Inside Diameter: <u>35 in = 2.92 ft</u>

Probe location up from conduit bottom: 0.29 x 2.92 ft = 0.85 ft
Probe location in from conduit side: 0.85 ft

Flow probe meter velocity readings, V (ft/s):
    Average of 5 readings from conduit bottom = 6.3 ft/s
    Average of 5 readings from conduit side = 6.7 ft/s
    Average velocity, <u>V = (6.3 + 6.7)/2 = 6.5 ft/s</u>

Measurement Example and Calculations for Full Pipe Flow - 2

Cross-sectional area of pipe, A (ft^2):

$A = (\pi \times D^2)/4$ where $\pi \sim 3.14$

$\underline{A = (3.14 \times 2.92^2)/4 = 6.69 \text{ ft}^2}$

Average flow in pipe, Q (cfs):

$Q = V \times A$

$Q = 6.5 \times 6.69 = 43.5 \text{ cfs}$

Flow in pipe, Q (gpm):

$Q = 43.5 \text{ cfs} \times 448.8 \text{ gpm/cfs} = 19,523 \text{ gpm}$

Measurement Example and Calculations for Partial Pipe Flow - 1

Pipe Inside Diameter, D: <u>35 in = 2.92 ft</u>

Flow depth in conduit, d: <u>17.5 in = 1.46 ft</u>

d/D = 0.5
Multiplication factor from table (next slide): 0.3927

Flow probe velocity measurements (2 tests at 0.6 time flow depth down from the water surface): 6.3 ft/s and 6.7 ft/s

Average flow velocity:

$$V = (6.3 + 6.7)/2$$

<u>V = 6.5 ft/s</u>
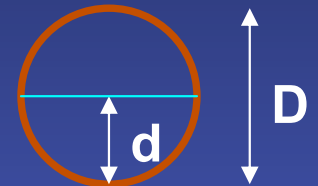
Cross-Sectional Area of Flow for Partially Full Pipes

$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$	$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$	$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$	$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$
0.01	0.0013	0.26	0.1623	0.51	0.4027	0.76	0.6405
0.02	0.0037	0.27	0.1711	0.52	0.4127	0.77	0.6489
0.03	0.0069	0.28	0.1800	0.53	0.4227	0.78	0.6573
0.04	0.0105	0.29	0.1890	0.54	0.4327	0.79	0.6655
0.05	0.0147	0.3	0.1982	0.55	0.4426	0.8	0.6736
0.06	0.0192	0.31	0.2074	0.56	0.4526	0.81	0.6815
0.07	0.0242	0.32	0.2167	0.57	0.4625	0.82	0.6893
0.08	0.0294	0.33	0.2260	0.58	0.4724	0.83	0.6969
0.09	0.0350	0.34	0.2355	0.59	0.4822	0.84	0.7043
0.1	0.0409	0.35	0.2450	0.6	0.4920	0.85	0.7115
0.11	0.0470	0.36	0.2546	0.61	0.5018	0.86	0.7186
0.12	0.0534	0.37	0.2642	0.62	0.5115	0.87	0.7254
0.13	0.0600	**0.38**	**0.2739**	0.63	0.5212	0.88	0.7320
0.14	0.0668	0.39	0.2836	0.64	0.5308	0.89	0.7384
0.15	0.0739	0.4	0.2934	0.65	0.5404	0.9	0.7445
0.16	0.0811	0.41	0.3032	0.66	0.5499	0.91	0.7504
0.17	0.0885	0.42	0.3130	0.67	0.5594	0.92	0.7560
0.18	0.0961	0.43	0.3229	0.68	0.5687	0.93	0.7612
0.19	0.1039	0.44	0.3328	0.69	0.5780	0.94	0.7662
0.2	0.1118	0.45	0.3428	0.7	0.5872	0.95	0.7707
0.21	0.1199	0.46	0.3527	0.71	0.5964	0.96	0.7749
0.22	0.1281	0.47	0.3627	0.72	0.6054	0.97	0.7785
0.23	0.1365	0.48	0.3727	0.73	0.6143	0.98	0.7816
0.24	0.1449	0.49	0.3827	0.74	0.6231	0.99	0.7841
0.25	0.1535	0.5	0.3927	0.75	0.6319	1	0.7850

Measurement Example and Calculations for Partial Pipe Flow - 2

Cross-sectional area of flow in pipe, A (ft²):

Multiplication factor = 0.3927 (from table)
$A = 0.3927 \times D^2$
$A = 0.3927 \times 2.92^2$
$A = 3.35$ ft²

Flow in pipe, Q (cfs):
$Q = V \times A$
$Q = 6.5 \times 3.35 = 21.8$ cfs

Flow in pipe, Q (gpm):
$Q = 21.8$ cfs $\times$ 448.8 gpm/cfs = 9,784 gpm

Orifice Manometer Method

- **Required Conditions:**
  - Pipe must be flowing full
  - Pipe must be level (horizontal) with a smooth interior and the end of the pipe cut square
  - Distance from orifice and any valves or fittings must be greater than 8 pipe diameters (minimum 4 ft recommended)
  - Must have 2 feet between pressure tap and orifice
  - Orifice must be true bore, smooth and with a diameter accurate to +/-0.001 inch
  - Orifice material should be 1/8 inch thick and rigid
  - Measurement points must be accessible
  - Not good for verification because changes head

Orifice Manometer Schematic for Applicability and Measurements - 1

RULER → ← GLASS TUBE
← RUBBER TUBE

← 2 FEET → ← 4 FEET OR MORE →
THIS DISCHARGE PIPE MUST BE LEVEL

RULER →

HEAD OF WATER IN TUBE

ORIFICE PLATE 1/16" THICK WITH HOLE OF EXACT SIZE

A PIPE CAP MACHINED THIS WAY MAY BE USED AS THE ORIFICE PLATE
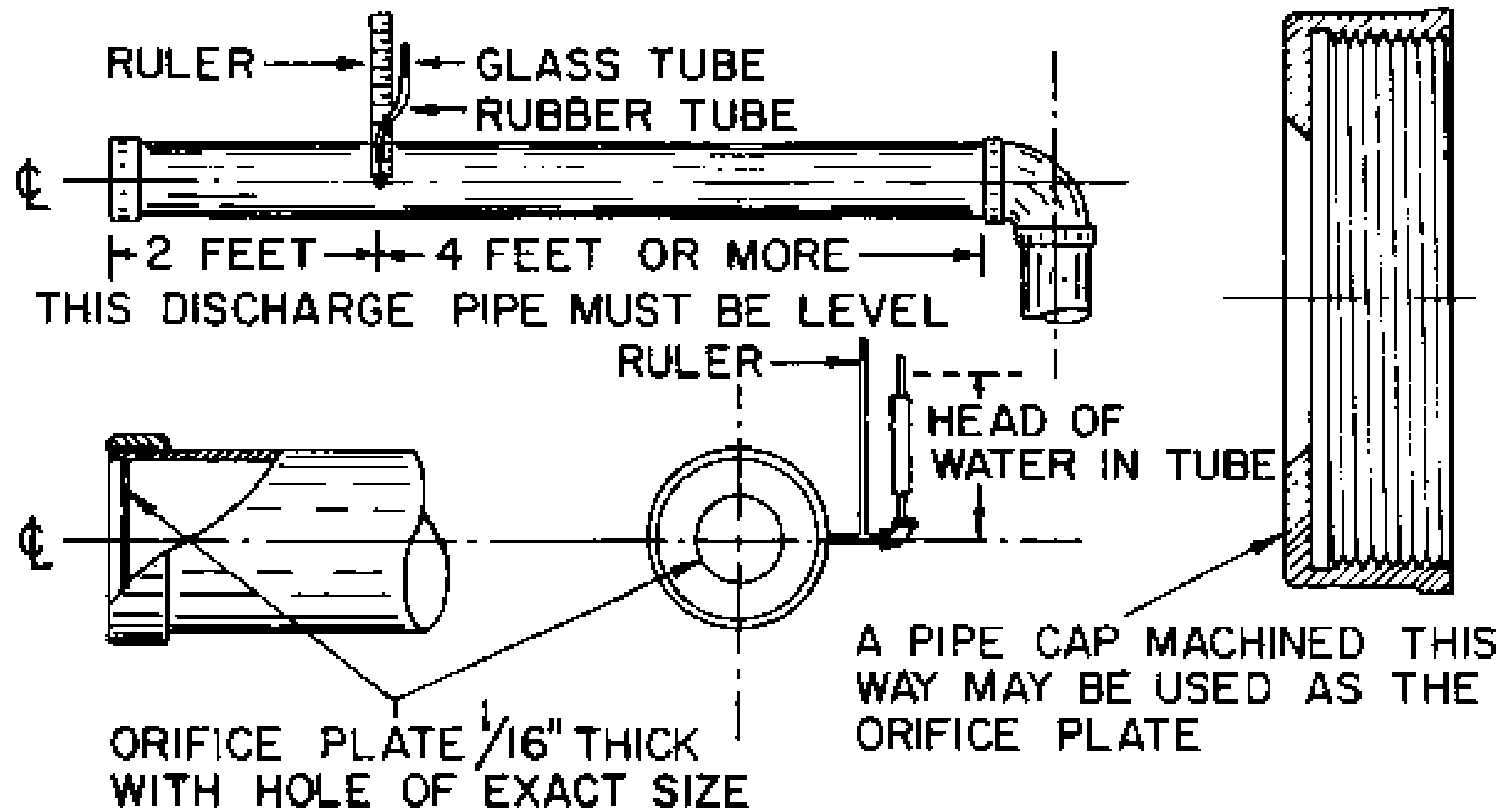
Orifice Manometer Schematic for Applicability and Measurements - 2
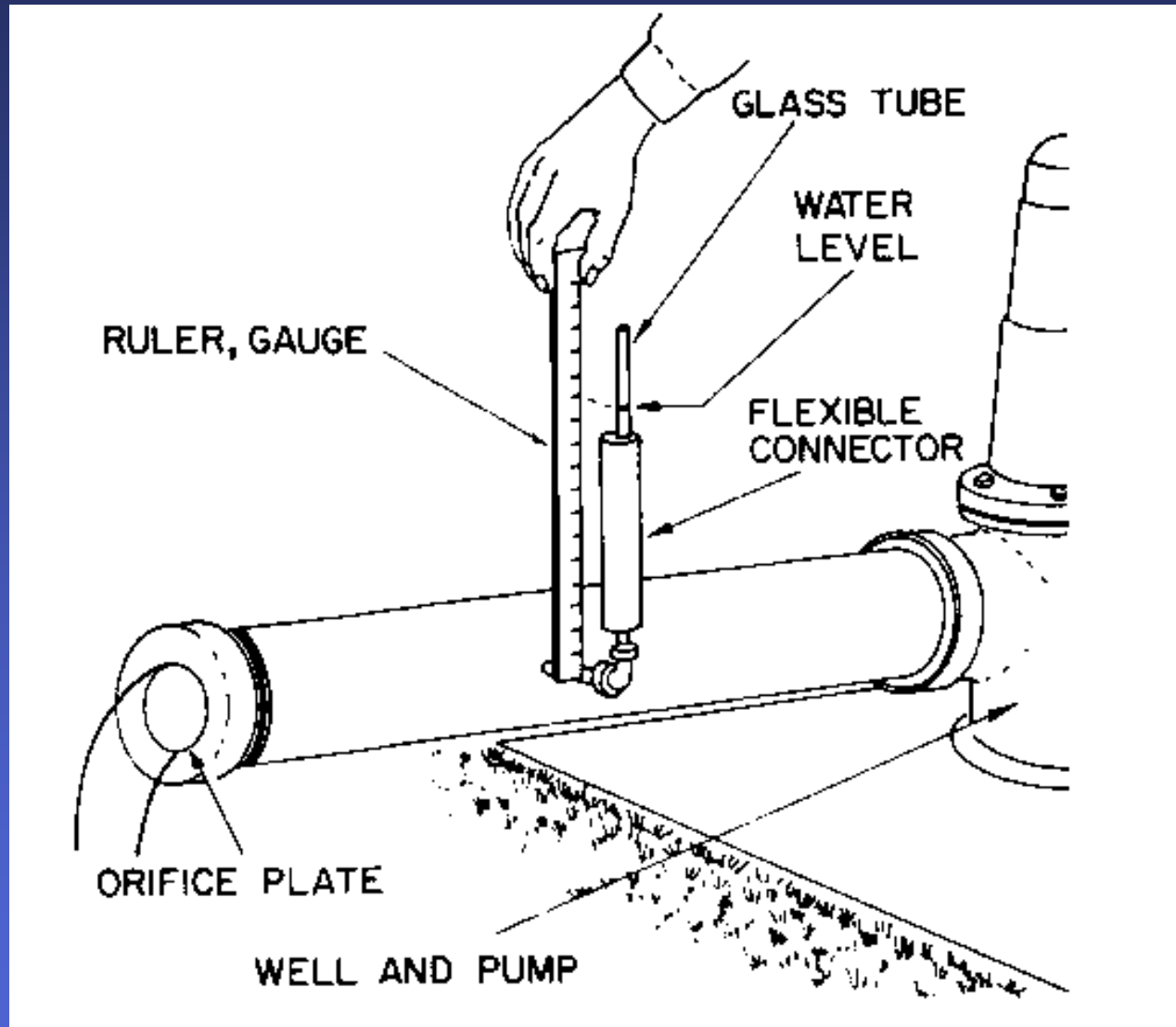
Test Procedure

- Allow flow in pipe to occur for at least 15 minutes prior to taking readings to ensure stable and consistent conditions, longer if pumping from a well where drawdown is a factor

- Select the size of the orifice so that manometer readings will be about 20 to 30 inches of water (California Method may be used to estimate flow in selection process)

- An air bleeder must be used to remove air from the top of the pipe at the orifice location prior to taking readings

- A manometer tap (for standpipe or manometer installation) must be placed in the pipe 2 feet upstream of the orifice

- Repeat hydraulic head measurements at least 3 times over a suitable time period to get a good average head readings

- Select coefficient "C" from the following table or from hydraulic handbooks

- Calculate flow, Q

Measurement Example and Calculations – 1

Pipe Inside Diameter: <u>4 in</u>

Orifice Diameter: <u>3 in</u>

Length of pipe section = <u>60 in</u>

Length/Diameter > 8?: <u>60/4 = 15, so acceptable</u>

Minimum 4 ft section available?: <u>yes</u>

Manometer readings (height of water in standpipe or manometer), in:

H1	H2	H3
5.75	6.0	6.25

Average hydraulic head, H (in):

H = (5.75 + 6.0 + 6.25)/3

<u>H = 6.0 in</u>

Measurement Example and Calculations - 2

Coefficient "C" from graph (next slide)(orifice diameter = 3 in):

    Ratio of orifice diameter to pipe diameter = 3 in/4 in = 0.75

    <u>C = 0.71</u>

Cross-sectional area of orifice:

    $A = \pi \times D^2/4$

    $A = \pi \times 3^2/4$

    <u>$A = 7.07 \text{ in}^2$</u>

Flow (Q) in pipe (gpm)

    $Q = 8.02 \times C \times A \times H^{0.5}$

    $Q = 8.02 \times 0.71 \times 7.07 \times 6^{0.5}$

    $Q = 98.6 \text{ gpm}$

Flow (Q) in pipe (cfs)

    Q = 98.6 gpm x 1 cfs/448.8 gpm = 0.22 cfs

C Coefficient for Orifices
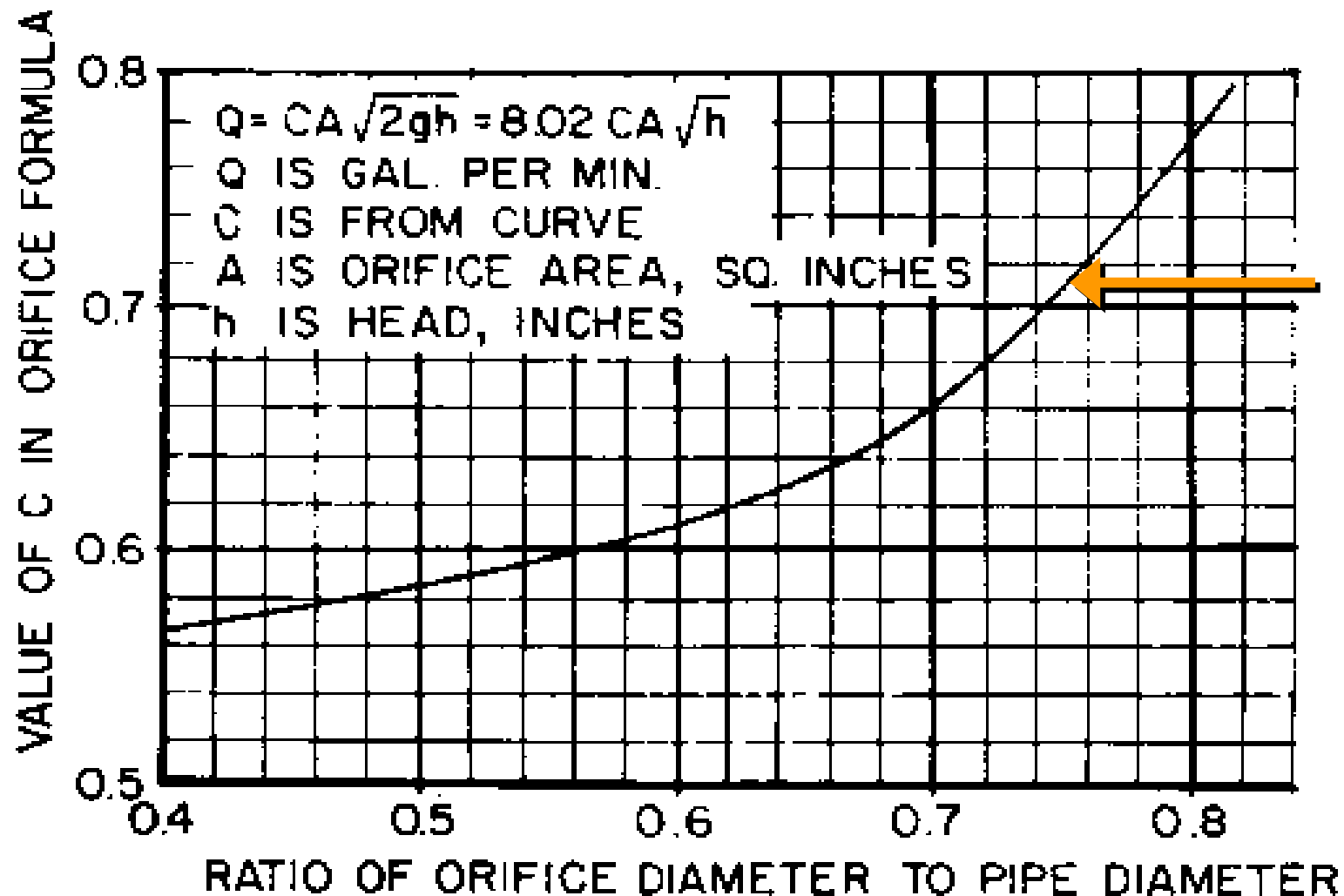
Chart showing value of C in orifice formula versus ratio of orifice diameter to pipe diameter.

$$Q = CA\sqrt{2gh} = 8.02\, CA\sqrt{h}$$

- Q IS GAL. PER MIN.
- C IS FROM CURVE
- A IS ORIFICE AREA, SQ. INCHES
- h IS HEAD, INCHES

Y-axis: VALUE OF C IN ORIFICE FORMULA (0.5 to 0.8)

X-axis: RATIO OF ORIFICE DIAMETER TO PIPE DIAMETER (0.4 to 0.8)

Pitot Tube Manometer Method

- **Required Conditions:**
  - Straight length of pipe
  - Flow profiles must be well-developed within the pipe
  - Must have 6 to 20 pipe diameters distance from all pumps, bends and fittings that could affect flow profile
  - Water must be fairly clean to avoid clogging and flow profile disturbances
  - Pipe must be exposed and accessible
  - May be used for full or partial pipe flow

Test Procedure – Full Pipe Flow

- **Determine pipe inside diameter, D (ft)**

- **Calculate cross-sectional area of flow, A (ft^2)**

- **Take at least 10 manometer readings across the pipe cross-section (recommend use of the 10-point method discussed in Section A**

- **Calculate the average manometer reading which represents the hydraulic head in the pipe**

- **Calculate flow**

Measurement Example and Calculations for Full Pipe Flow - 1

Pipe Inside Diameter: <u>48 in = 4 ft</u>
Length of pipe section = <u>24 ft</u>
Length/Diameter > 6?: <u>24/4 = 6, so acceptable</u>

Manometer readings, H (in):

H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
16.9	17.3	17.0	16.7	17.5	17.7	17.6	17.8	17.9	18.3

Average hydraulic head through test section, ft:
$$H = (H1 + H2 + H3 + \ldots + H10)/10$$
H = 17.47 in
<u>H = 17.47 in x 1ft/12 in = 1.46 ft</u>

Flow velocity in pipe, V (ft/s)
$$V = (2 \times g \times H)^{0.5}; \text{ where g is the acceleration due to gravity}$$
$$V = (2 \times 32.2 \text{ ft/s}^2 \times 1.46 \text{ ft})^{0.5}$$
<u>V = 9.69 ft/s</u>

Measurement Example and Calculations for Full Pipe Flow - 2

Cross-sectional area of pipe, A (ft^2):

$A = (\pi \times D^2)/4$; where $\pi \sim 3.14$

$A = (3.14 \times 4^2)/4$

$\underline{A = 12.56 \ ft^2}$

Flow in pipe, Q (cfs):

$Q = V \times A$

$Q = 9.69 \times 12.56$

$Q = 121.7 \ cfs$

Flow in pipe, Q (gpm):

$Q = 121.7 \ cfs \times 448.8 \ gpm/cfs = 54,619 \ gpm$

Test Procedure – Partially Full Pipe Flow

- Determine pipe inside diameter, D (ft)

- Determine depth (d, ft) of flow in pipe using a chalk stick inserted in the tap opening and moving it back and forth across the pipe bottom (perpendicular to flow) while keeping it vertical (as long as stick is perpendicular to flow path, wetted chalk mark will show depth of water at center of the pipe)

- Calculate d/D and locate multiplication factor via the in standard table in Section C, Appendix C, or in the next slide

- Calculate cross-sectional area of flow as D^2 x multiplication factor or use the stream gauging techniques shown in the table in Section C, Appendix C and the previous slide

- Measure velocity according to procedures for full pipe flow ensuring inclusion of side to side and up and down points

- Calculate flow, Q (cfs)

Measurement Example and Calculations for Partial Pipe Flow - 1

Pipe Inside Diameter: 48 in = 4 ft

Length of pipe section = 18 ft

Length/Diameter > 6?: 18/3 = 6, so acceptable

Manometer readings, H (in):

H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
16.9	17.3	17.0	16.7	17.5	17.7	17.6	17.8	17.9	18.3

Average hydraulic head through test section, ft:

H = (H1 + H2 + H3 + … + H10)/10

H = 17.47 in

H = 17.47 in x 1ft/12 in = 1.46 ft

Flow velocity in pipe, V (ft/s)

$V = (2 \times g \times H)^{0.5}$; where g is the acceleration due to gravity

$V = (2 \times 32.2 \ ft/s^2 \times 1.46 \ ft)^{0.5}$

V = 9.69 ft/s

Measurement Example and Calculations for Partial Pipe Flow - 2

Cross-sectional area of flow in pipe, A (ft^2):

D = 48 in = 4 ft

d = 24 in = 2 ft

d/D = 24/48 = 0.50

Multiplication factor = 0.3927 (from table)

A = 0.3927 x D^2

A = 0.3927 x 4^2

A = 6.28 ft^2

Flow in pipe, Q (cfs):

Q = V x A
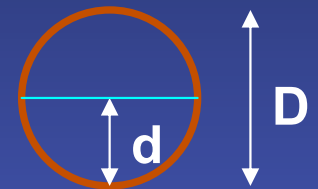
Q = 9.69 x 6.28 = 60.85 cfs

Flow in pipe, Q (gpm):

Q = 60.85 cfs x 448.8 gpm/cfs = 27,309 gpm

Propeller Meter Method

- **Required Conditions:**
  - **Straight length of pipe must be flowing full**
  - **Meter must be calibrated for the specific inside diameter of the pipe prior to measuring**
  - **Manufacturer's specifications for mounting, including distance from pump, bends and other flow disturbing items must be followed during measurement**

Test Procedure

- Secure the meter so that the propeller of the meter is in the exact center of the pipe's circular cross-section

- Operate the system until flow stabilizes before beginning the test

- If using a totalizing meter, record the reading on the meter before starting the test (flow should still be occurring after stabilizing)

- Run the test for a 10-minute period and record the ending value on the flow totalizer

- Subtract the beginning reading from the final reading to get the total flow volume

- Divide the totalized flow volume, generally in gallons, by 10 to get gallons per minute (gpm)

- If the meter does not have a totalizer, record several flow velocity readings (gpm) over the 10-minute period and simply average the values

Measurement Example and Calculations

Pipe Inside Diameter: <u>6 in</u>
Length of pipe section = <u>48 in</u>
Length/Diameter > manufacturer's specs?: <u>48/6 = 8, so acceptable</u>

Test duration, T = 10 minutes
Totalizer reading at start: 12,070 gallons
Totalizer reading at end: 18,185 gallons

Total flow volume over 10-minute period:
   Vol. = 18,185 – 12,070
   Vol. = 6,115 gallons

Flow (Q) in gpm:
   Q = Vol/T
   Q = 6,115 gal/10 minutes
   Q = 6,115 gpm

Flow (Q) in cfs = 6,115 gpm x 1 cfs/448.8 gpm = 13.63 cfs

Trajectory Method

- **Required Conditions:**
    - Straight length of pipe, must be level (horizontal)
    - The end of the discharge pipe must be flowing full (no gap)
    - The discharge end of the pipe must be cut square
    - The straight length of pipe must be 8 to 10 pipe diameters long
    - Access to measurement points must be present

Test Procedure

- Check the level of the pipe using a carpenter's level
- Check the end of the pipe conditions using a carpenter's square or level in both horizontal and vertical directions and adjust as necessary
- Allow flow in pipe to occur for at least 15 minutes to obtain stable and consistent flow prior to taking measurements
- Measurements necessary are the trajectory of the discharge stream from the pipe end (vertical and horizontal distances using a straight edge or a graduated square)
- Mathematical simplifications to the method can be made if the vertical distance (top of pipe to top of discharge stream) is preset to 4 or 12 inches
- Repeat the measurements at least 3 discrete times
- Calculate flow
- Also know as the Purdue Method

Measurement Example and Calculations - 1

Pipe Inside Diameter: <u>4 in</u>
Length of pipe section = <u>32 in</u>
Length/Diameter > 8 to 10?: <u>32/4 = 8, so acceptable</u>
Pipe flowing full at outlet?: <u>must be yes</u>
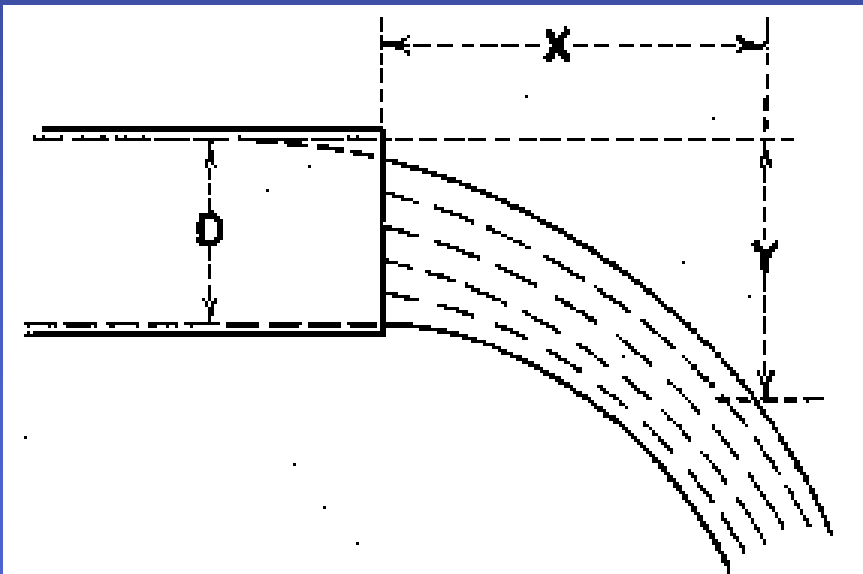
Cross-sectional area of pipe:

$A = \pi \times D^2/4$, $\pi \sim 3.14$
$A = 3.14 \times 4^2/4$
$A = 12.56 \text{ in}^2$
$A = 12.56 \text{ in}^2/144 \text{ in}^2/1 \text{ ft}$
<u>$A = 0.0872 \text{ ft}^2$</u>

Measurement Example and Calculations - 2

Trajectory measurements, X and Y (in):

    X1 = 8   Y1 = 4.0

    X2 = 7   Y2 = 4.0

    X3 = 6   Y3 = 4.0

    X_{ave} = 7.0 in Y_{ave} = 4.0 in

Convert average X and Y to feet:

    $\underline{X_{ave} = 7/12 = 0.58 \text{ ft}}$

    $\underline{Y_{ave} = 4/12 = 0.33 \text{ ft}}$

Flow velocity in pipe, V (ft/s):

    $V = X \times g^{1/2}/(2 \times Y)^{1/2}$, g = the gravitational constant ~ 32.2 ft/s²

    $V = g^{1/2} \times X/(2 \times Y)^{1/2}$

    $V = 32.2^{1/2} \times 0.58/(2 \times 0.33)^{1/2}$

    $V = 5.67 \times 0.58/(2 \times 0.33)^{1/2}$

    $\underline{V = 4.05 \text{ ft/s}}$

Measurement Example and Calculations – 3

Flow (Q) in pipe (ft/s):

$Q = V \times A$

$Q = 4.05 \text{ ft/s} \times 0.0872 \text{ ft}^2$

$\underline{Q = 0.3532 \text{ cfs}}$

Convert Q to gpm:

$Q = 0.3532 \text{ cfs} \times 448.8 \text{ gpm/1 cfs}$

$Q = 158.6 \text{ gpm}$

NOTE: Flow can be read directly from charts or tables given pipe diameter and X and Y readings

SIMPLIFICATION: If X readings are taken in inches with Y always at 12 in, the flow equation simplifies to:

$Q, \text{gpm} = 0.818 \times D^2 \times X$; D and X in inches

Ultrasonic and Other External Flow Meter Method

- **Required Conditions:**
  - Straight length of pipe
  - The pipe is exposed and accessible
  - The length of pipe must generally be 6 to 10 pipe diameters away from pumps, bends or other items that could disrupt flow patterns (always follow meter manufacturer's recommendations)
  - The meter must have been calibrated within an acceptable period of time (manufacturer's specifications or as needed after any handling incident that may affect proper operation)
  - The pipe must be flowing full at the point of measurement
  - Pressurized irrigation systems will have full flow conditions when properly designed, maintained and operated

Test Procedure

- **Ensure that pipe length is adequate**

- **Run system for at least 15 minutes prior to taking measurements to allow flow stabilization and minimal drawdown effects**

- **Take at least 5 discrete velocity readings over a 5 to 10 minute period of time**

- **Determine cross-sectional area of pipe (use inside diameter)**

- **Calculate flow, Q**

Measurement Example and Calculations - 1

Pipe Inside Diameter: 24 in = 2 ft
Length of pipe section = 144 in
Length/Diameter > 6 to 10?: 144/24 = 6, so acceptable
Pipe flowing full at outlet?: must be yes

Receive/Send Transducer

Flow

Upstream Signal Path

Downstream Signal Path

Receive/Send Transducer
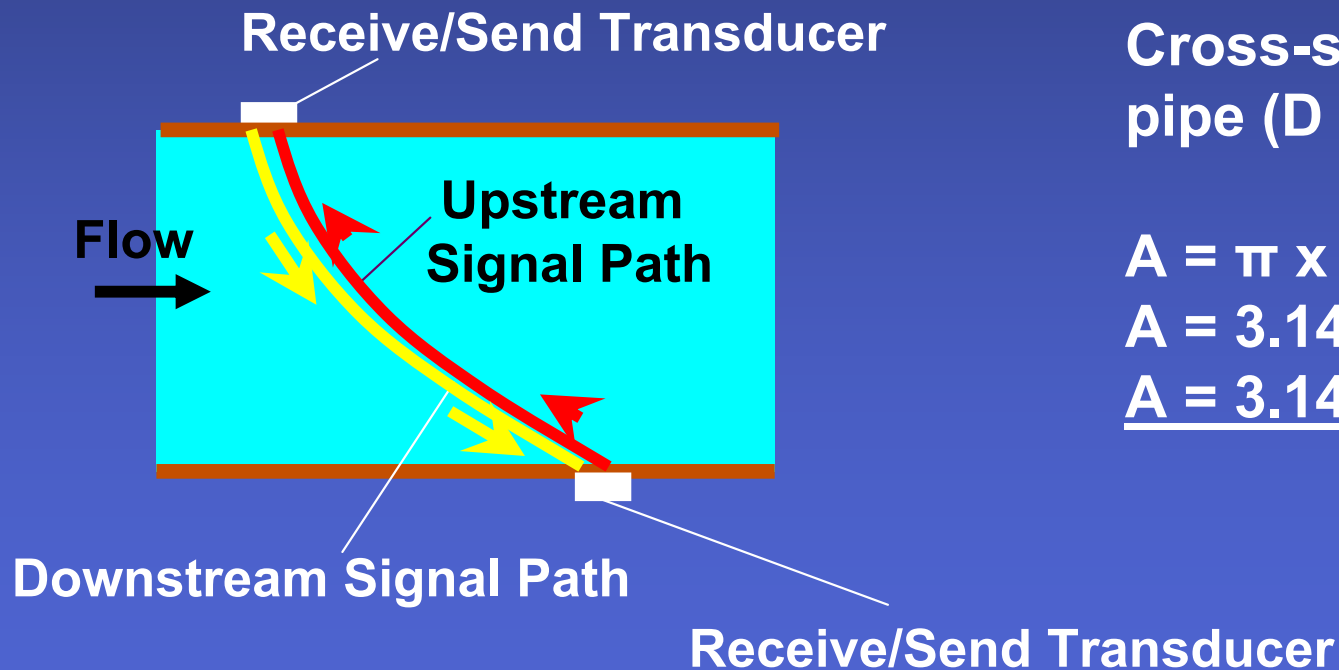
Cross-sectional area of pipe (D in ft):

$A = \pi \times D^2/4$, $\pi \sim 3.14$
$A = 3.14 \times 2^2/4$
$A = 3.14 \text{ ft}^2$

Measurement Example and Calculations - 2

Flow velocity readings (ft/s):

T1 = 1:00	V1 = 8.56
T2 = 1:01	V2 = 8.55
T3 = 1:02	V3 = 8.57
T4 = 1:03	V4 = 8.57
T5 = 1:04	V5 = 8.55
	V_{ave} = <u>8.56 ft/s</u>

Average flow (Q) in pipe (cfs):

Q = V x A

Q = 8.56 ft/s x 3.14 ft^2

Q = 26.88 cfs

Average flow in pipe (gpm):

Q = 26.88 cfs x 448.8 gpm/cfs

Q = 12,063 gpm

Vertical Pipe Method

- **Required Conditions:**
  - Straight length of pipe must be vertical
  - Pipe must discharge to open air
  - Must have access to pipe discharge end

Vertical Pipe Method Schematic for Applicability and Measurement
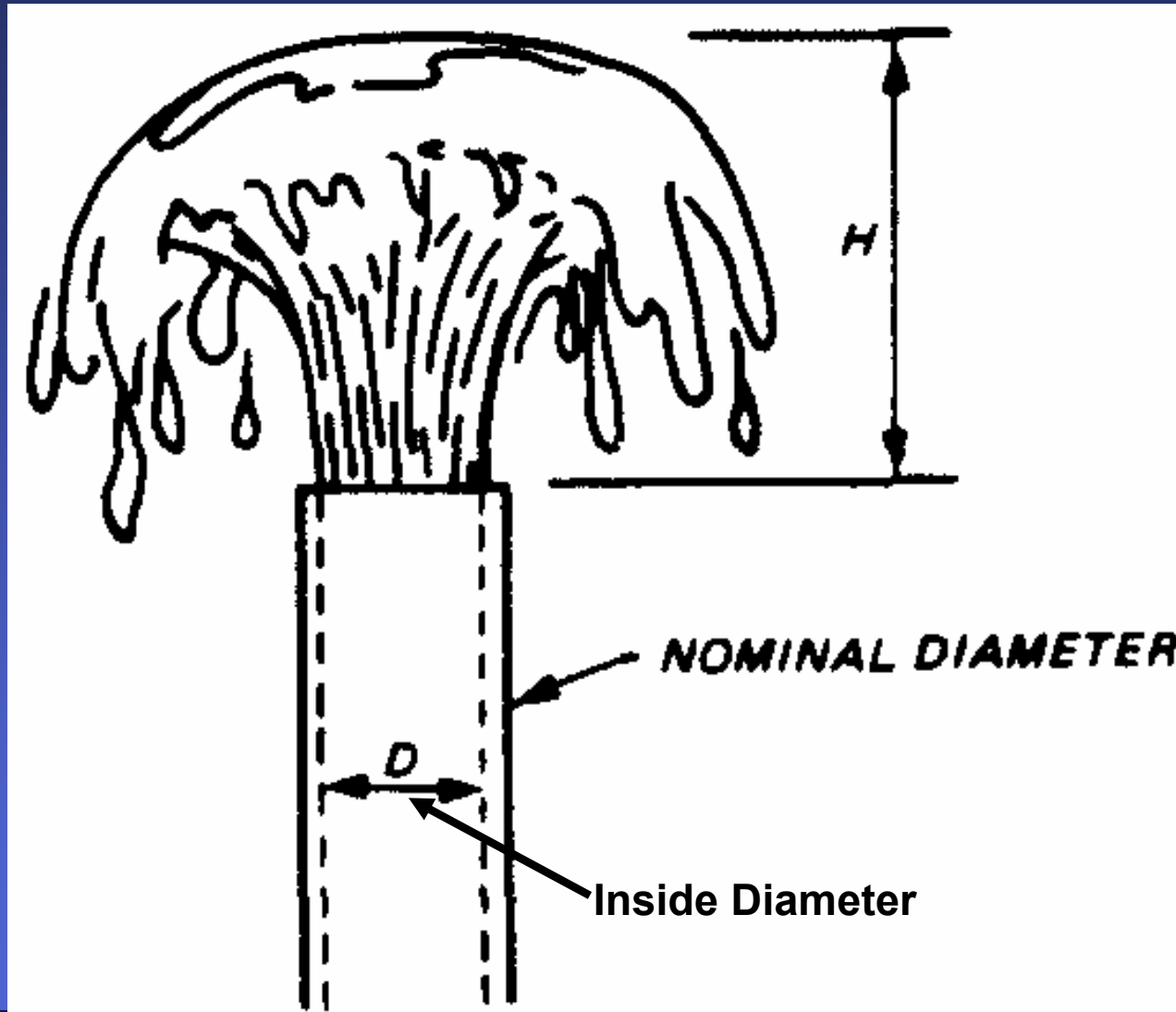
Test Procedure

- Determine the inside diameter of the pipe

- Run system for at least 15 minutes prior to taking measurements to allow flow stabilization and minimal drawdown

- Use a straight edge or carpenter's square to measure vertical rise of water spout (hydraulic head) ensuring that the measuring tool is inline with the vertical pipe

- Using a carpenter's level to make the measurement might be best; simply use the level to ensure the level is vertical and mark the height of the water spout on the level and use a ruler to measure the marked distance

- Take at least 3 discrete head readings over a 5 to 10 minute period of time and obtain an average "H"

- Refer to a table of H vs Q values to determine flow

- Calculate flow, Q

Measurement Example and Calculations - 1

Pipe inside diameter (I.D.): <u>4 inches</u>
Pipe is vertical with no lean?: <u>answer must be "yes"</u>

Rise of water spout above top of pipe, H (in):

> H1 = 6
> H2 = 5
> H3 = 7
> H_{ave} = <u>6.0 in</u>

Refer to table:

> I.D. = 4 in
> H = 6.0 in
> <u>Q = 205 gpm</u>

Convert to cfs if desired:
Q = 205 gpm x 1 cfs/448.8 gpm
Q = 0.46 cfs

Measurement Example and Calculations - 2

Table of Flow (Q) Given Pipe I.D. and H

Pipe I.D. (in)	Rise of Water Spout Above Edge of Pipe (inches)										
	3	3.5	4	4.5	5	5.5	6	7	8	10	12
2	38	41	44	47	50	53	56	61	65	74	82
3	81	89	96	103	109	114	120	132	141	160	177
4	137	151	163	174	185	195	205	222	240	269	299
6	318	349	378	405	430	455	480	520	560	635	700
8	567	623	684	730	776	821	868	945	1020	1150	1270
10	950	1055	1115	1200	1280	1350	1415	1530	1640	1840	2010

Measurement Example and Calculations - 3

Alternative equation: $Q = 5.68 \times K \times D^2 \times H^{0.5}$; D and H in inches

   K = coefficient that ranges from 0.87 for 2 in diameter
   pipes to 0.97 for 6 in diameter pipes as long as H is
   between 6 in and 24 in

Pipe inside diameter (D): <u>4 in</u>
Rise of water spout above top of pipe, H (in): H_{ave} = <u>6.0 in</u>

Interpolate (linear) for K:

   $K_{4 \text{ in pipe}}$ = 0.87 + [(4-2)/(6-2)] x (0.97 − 0.87)
   K = 0.92

Calculate flow, Q:

   $Q = 5.68 \times 0.92 \times 4^2 \times 6^{0.5}$
   Q = 205 gpm

Convert Q to cfs if desired:
Q = 205 gpm x 1 cfs/448.8 gpm
Q = 0.46 cfs

Volumetric Flow Method
(Single Outlet Only, NOT for sprinkler/drip average flow)

- **Required Conditions:**
  - **Flow in pipe is low enough that it can fill a reasonable sized container in no less than 15 seconds with no splashing**
  - **The pipe is small and positioned in such a way that flow can be temporarily directed to the collection container**
  - **Method can be used on either a volume or a weight basis**
  - **Be careful about accounting for injected liquids prior to the pipe discharge (will need to be subtracted out or change in water specific gravity will need to be accounted for)**
  - **If using volumetric method, collection container must be small enough to be easily handled**
  - **If using weight method, collection container must be small enough to be weighed on an accurate scale**

Test Procedure

- Determine whether there is any substantial chemical injection into the flow stream prior to the collection point

- If injection is occurring be sure to subtract injected volume that occurred over the test period (volume method)

- If injection is occurring, be sure to determine the specific gravity of the combined liquids to enable correction (weight method)

- Place collection container at discharge end of pipe so that it will capture all flow

- The container should be of known volume or marked at a point of known volume if using the volumetric method and known weight if using weight method)

- Use a stop watch or watch with a second hand to determine the time it takes to fill the container (known volume if volumetric)

- Take at least 3 discrete measurements over a 5 to 10 minute period of time Calculate flow, Q

Measurement Example and Calculations - 1

Pipe inside diameter (I.D.): <u>4 in</u>

Flow was redirected to the container via a temporary PVC pipe that did not add hydraulic head to the system

No chemical injection was taking place

Container weight information:
      Weight (empty): 50 lbs
      Weight (full): 1719 lbs

Container volume information:
      Volume of container up to mark: 200 gallons

Time to fill 200 gallons: T1 = 18 s   T2 = 20 s   T3 = 22 s
                    T_{ave} = 20 s

Measurement Example and Calculations - 2 Weight Method

Weight of water in container (empty container weighed 50 lbs):

1719 lbs – 50 lbs = 1669 lbs

Convert weight of water to volume:

Vol_{water} = lbs water/specific gravity of water

Vol_{water} = 1669 lbs/62.4 lbs/ft^3

Vol_{water} = 26.75 ft^3

Flow (Q) from pipe:

$Q = Vol_{water}$, ft^3/T, s

Q = 26.75 ft^3/20 s

Q = 1.34 cfs

Convert flow (Q) to gpm:

Q = 1.34 cfs x 448.8 gpm/cfs

Q = 600 gpm

Measurement Example and Calculations - 3
Volume Method

Time to fill 200 gallon container, T: <u>20 s</u>

Flow (Q) from pipe:

$Q = Vol_{water}, ft^3/T, s$

$Q = 200 \text{ gal}/20 \text{ s}$

$Q = 10 \text{ gal/s} \times 60 \text{ s}/1 \text{ min}$

$Q = 600 \text{ gpm}$

Convert flow (Q) to cfs if desired:

$Q = 600 \text{ gpm} \times 1 \text{ cfs}/448.8 \text{ gpm}$

$Q = 1.34 \text{ cfs}$

Weir Method

- **Required Conditions:**
  - A typical weir is a flashboard riser with boards installed
  - Weir must be rectangular in shape with water flowing freely over its top
  - Weir must be level (horizontal)
  - Velocity of flow approaching the weir must be low
  - Upstream channel must be free of trash
  - Water level upstream of the weir must be deep enough to be able to measure the hydraulic head (H) over the weir top
  - The water level downstream of the weir must be below the top of the weir so as not to affect flow over the weir
  - For other types of weirs and flow conditions (submerged, v-notch, etc.), a Florida registered P.E. should be retained to prepare and submit measurement plans to the SFWMD for approval

Test Procedure

- Measure the height of the upstream water level above the top of the weir (hydraulic head, H)

- Upstream H measurement should be taken at least 1 weir width upstream of the weir

- Measure the width of the weir

- All measurements should be no worse than to the nearest ½ inch but should easily be better

- The weir coefficient must be verified for applicability if the riser or channel width is less than 3 times the width of the weir

Flashboard Riser with Boards as a Weir Structure

Height of water above weir crest

Width of weir crest

Measurement Example and Calculations - 1

Weir dimensions:

Length of crest = <u>2.5 ft</u>

Top of weir elevation = <u>9.65 ft</u>

Upstream water surface elevation = <u>10.95 ft</u>

<u>*NOTE:*</u> If height of water over weir crest can be measured directly, weir top and upstream elevation measurements are not necessary

Head on weir (H) if not measured directly:

H = Water surface elevation, ft – Top of weir elevation, ft

H = 10.95 ft – 9.65 ft

H = 1.30 ft

Measurement Example and Calculations - 2

Weir equation:

Q, cfs = C x L, ft x (H, ft)$^{1.5}$; where C (weir coefficient) and exponent 1.5 are curve-fitting parameters that may need to be changed given different configurations

Weir coefficient C = 3.13

Flow (Q) in cfs:

$Q = 3.13 \times 2.5 \text{ ft} \times 1.30^{1.5}$

$Q = 11.60$ cfs

Flow in gpm if desired:

$Q = 11.60$ cfs x 448.8 gpm/cfs

$Q = 5,205$ gpm

Using Pump Curves

- **Pump Performance Curves**
  - **Provides flow as function of total dynamic head and pump propeller RPM**
  - **Indicates pump and efficiency**
  - **Provided by manufacturer, but needed to be verified periodically due to wear or modifications**
  - **Installation must be within manufacturer's specifications**
- **Requires following measurements**
  - **Suction and discharge heads**
  - **Pump RPM**
  - **Pump curves may be fitted to equations to directly calculate flow**

Example Pump Performance Curves

18" Axial Flow
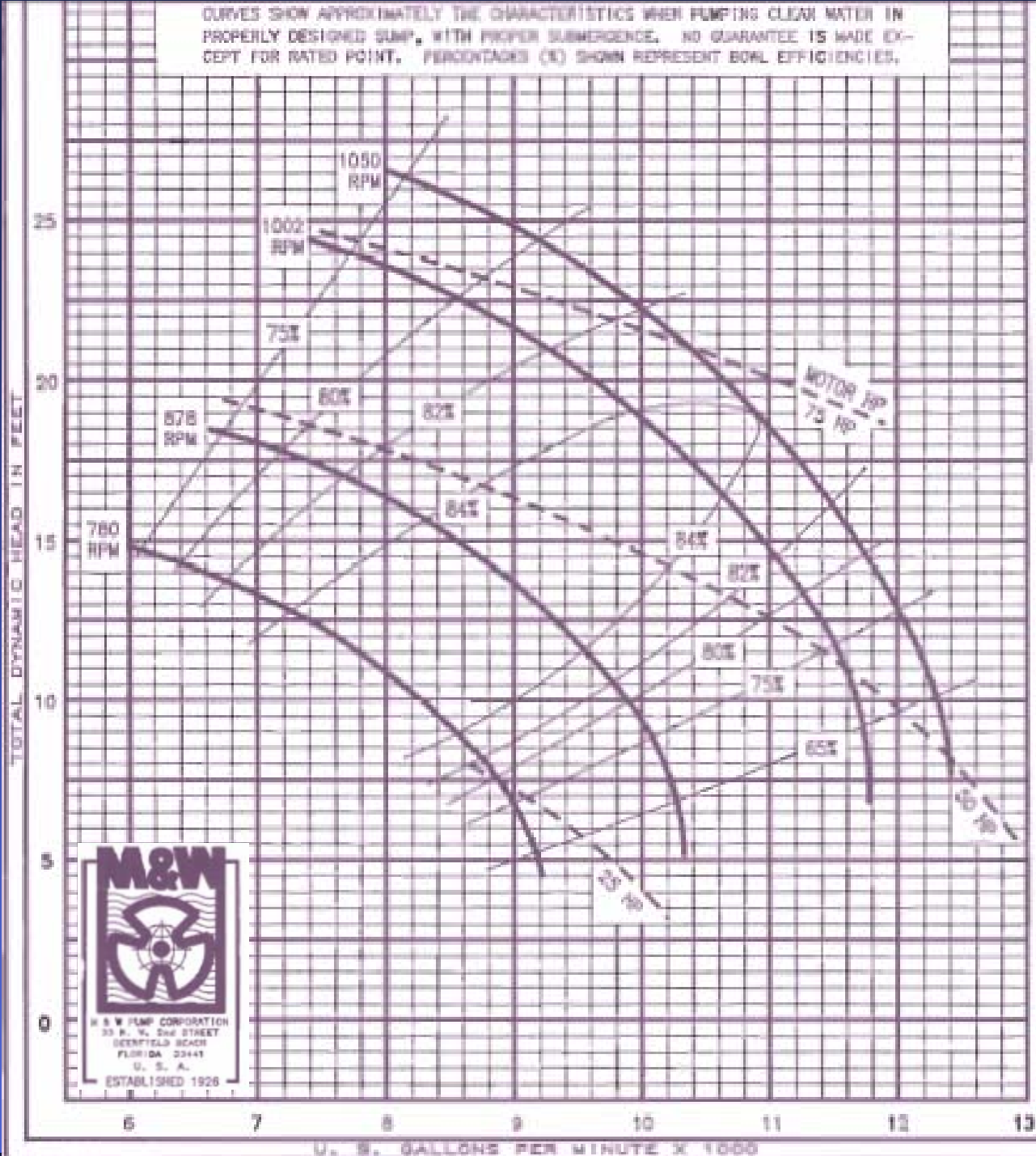
Specific Examples of Flow Monitoring and Verification

1. *Closed conduits in pressurized systems*
2. *Closed conduits in axial flow pump systems*
3. *Open channel flow with gate control structure*
4. *Open channel flow in farm canals and ditches*

The following examples are not implied to be the best methods for the given situations. The examples illustrate the logic, measurements and calculations that must go into selecting and implementing monitoring and flow verification methods.

Pressurized Conduits - 1

Citrus irrigation system with submersible turbine well pump powered by a diesel engine
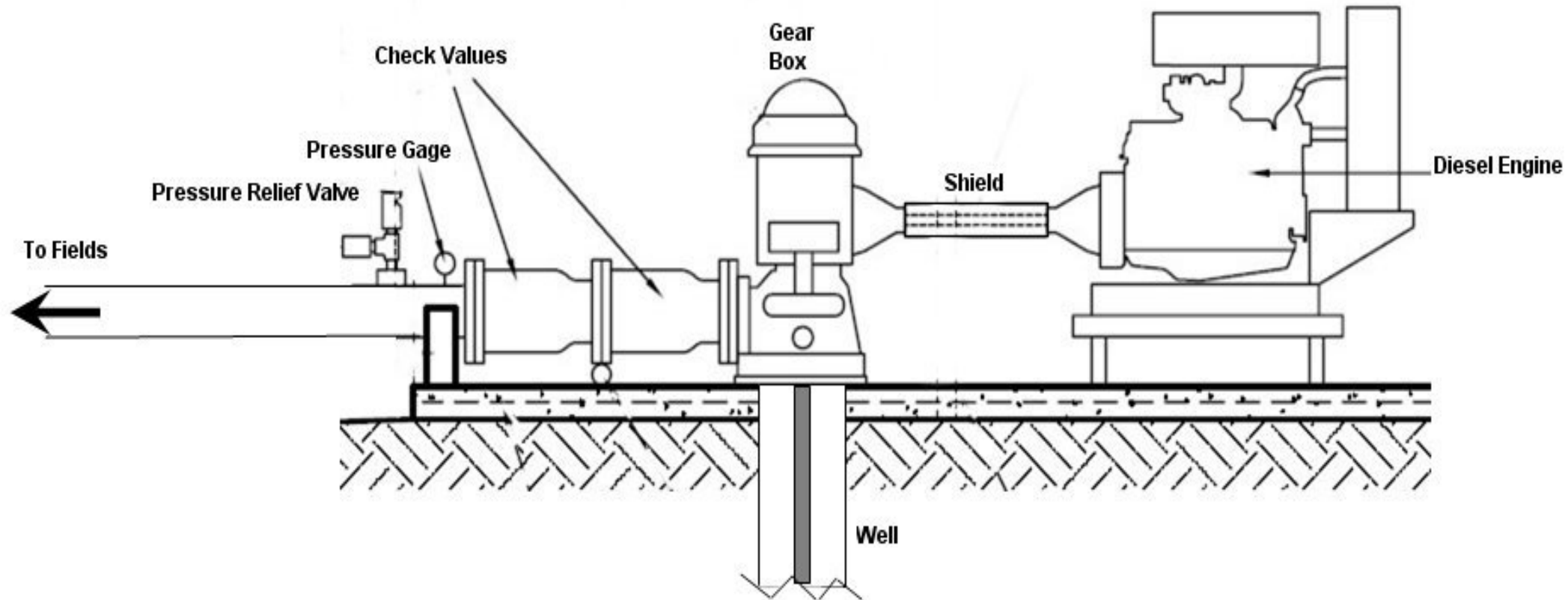
Pressurized Conduits - 2

- **Monitoring Method Selection**
  - **Candidates**
    - **Pump performance curve**
    - **Mechanical in-line flow meter**
    - **Ultrasonic**

Pump Performance Method

  - **Pros**
    - **No modifications to system**
    - **Data (pressure, RPM, runtimes) fairly easy to record**
  - **Cons**
    - **RPM needs to be recorded due to diesel engine**
    - **Calibration verification tests required and complicated by diesel engine**
    - **Variable unknown drawdown in well, affects TDH**

Pressurized Conduits – 3

Mechanical Flowmeter
- Pros
  - Available pipe section for installation requiring minimal modifications to system
  - Very easy to record flow data
- Cons
  - Moderately expensive
  - Flowmeter calibration required frequently

Ultrasonic
- Pros
  - Available pipe section provides for easy installation
  - Automatic data recording if datalogger is used
- Cons
  - Expensive
  - Costly calibration verification tests required

Pressurized Conduits - 5

Mechanical flowmeter selected because of ease of operation and minimal modification for installation

Equipment specifications:

- Flow range
- Accuracy

  Controlled by manufacturer

- Pipe diameter
- Reliability/Durability
- Maintenance requirements

Available manufacturers

- See Guidebook Sections D and E

Pressurized Conduits - 6

FLOW MONITORING DATA ENTRY SHEET

FARM NAME _____

PERMIT NO. _____

SITE DESCRIPTION _____

_____

DATE	TIME	OPERATOR INITIALS	FLOWMETER READING (Gallons x 1000)	COMMENTS

Pressurized Conduits - 7

FLOW MONITORING MAINTENANCE LOG SHEET

FARM NAME _____

PERMIT NO. _____

SITE DESCRIPTION _____

_____

DATE	TIME	FLOWMETER CALIBRATION	FLOWMETER CORRECTION FACTOR	OTHER ACTIVITIES	OPERATOR INITIALS

Pressurized Conduits - 8

Flowmeter Calibration/Verification

Selection of Secondary Flow Measurement Device:

- **Options:**
    - **Mechanical, ultrasonic, pitot tube, dye fluorometry**
- **Availability of straight pipe section makes a transit-time ultrasonic flowmeter a good selection**
- **Verify calibration status of transit-time flowmeter**

Calibration/Verification Run

- **Properly attach to outside of pipe and take several readings over several hours (1 hr minimum) under normal operating conditions**
- **Compare results and make corrections to the primary flowmeter readings**

Pressurized Conduits - 9

Calibration/Verification – Example Setup and Results
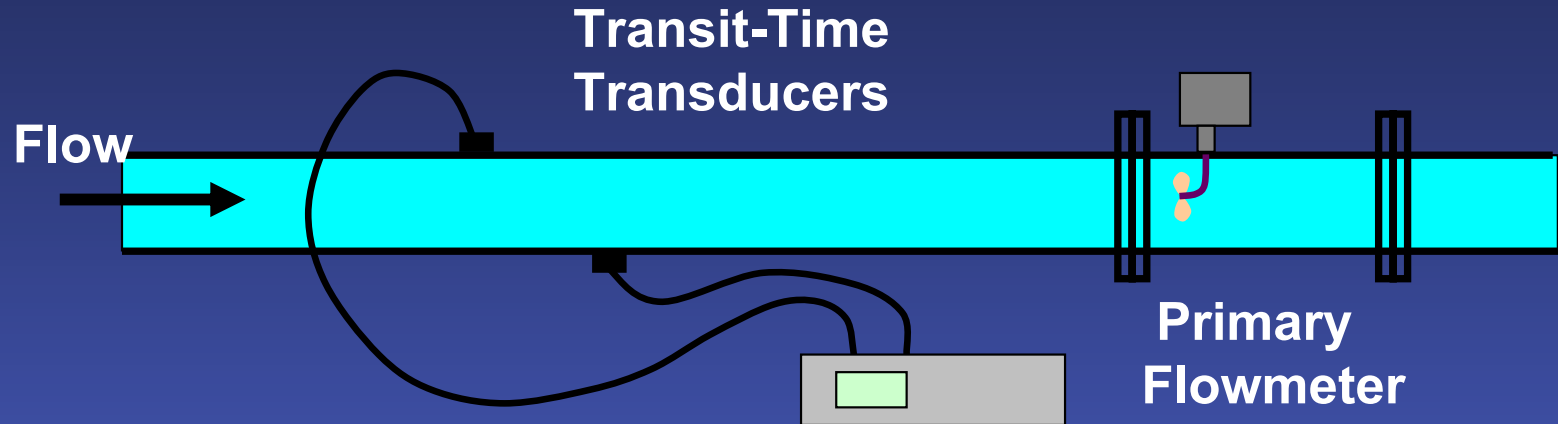
Time	Ultrasonic Reading	Flowmeter	
(hr)	(gpm)	(Gallonsx1000)	(gpm)
0	932	12759.0	
1	941	12816.3	955
2	939	12874.0	962
3	933	12931.4	957
4	929	12988.9	958
average	935		958
Error/Correction			2.5%
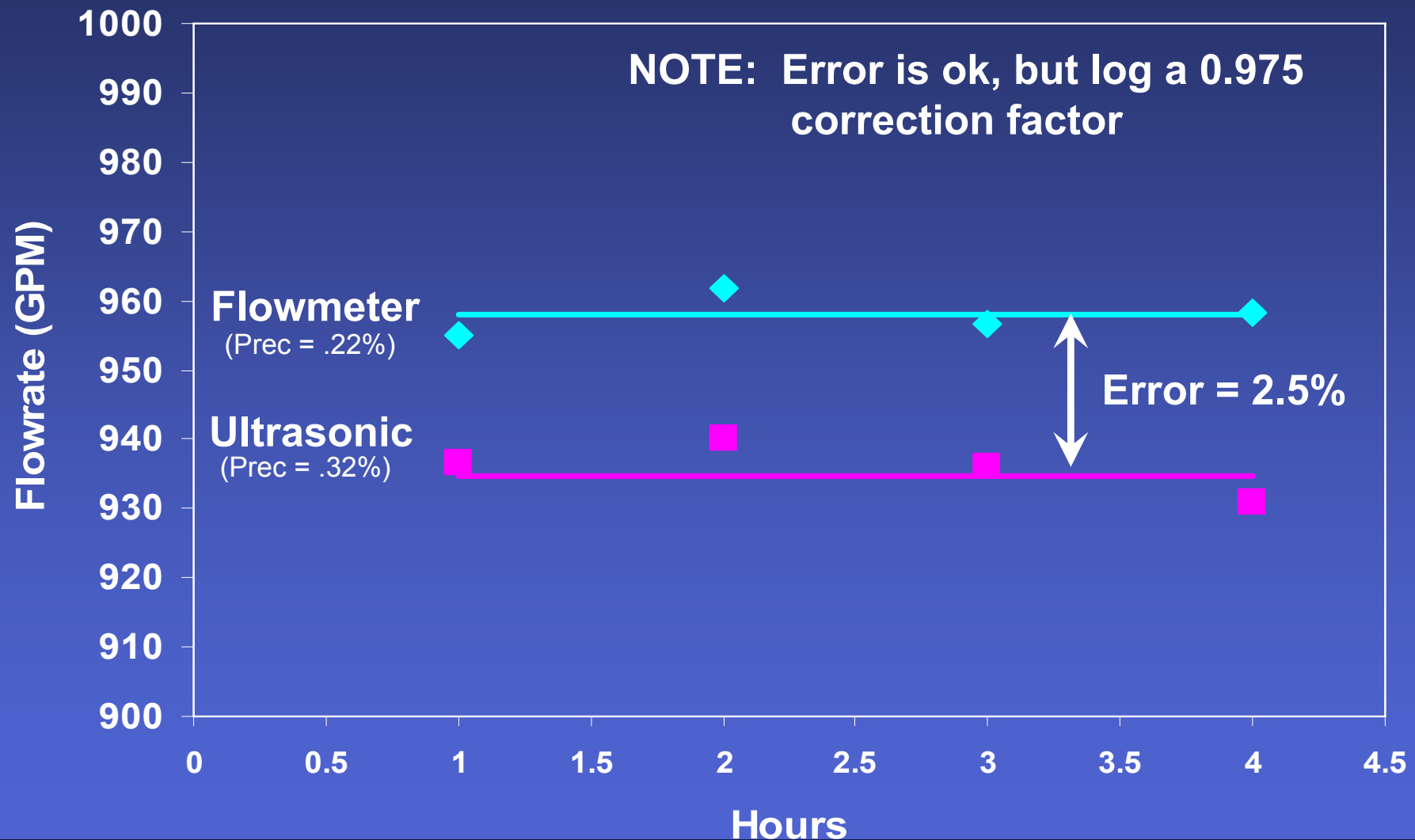
Axial Flow Pump Conduits - 1

Lift pump station for irrigation water supply from District canal, diesel engine on an 18" axial flow pump

Air Release Valve

Staff gage

Staff gage

sfwmd.gov
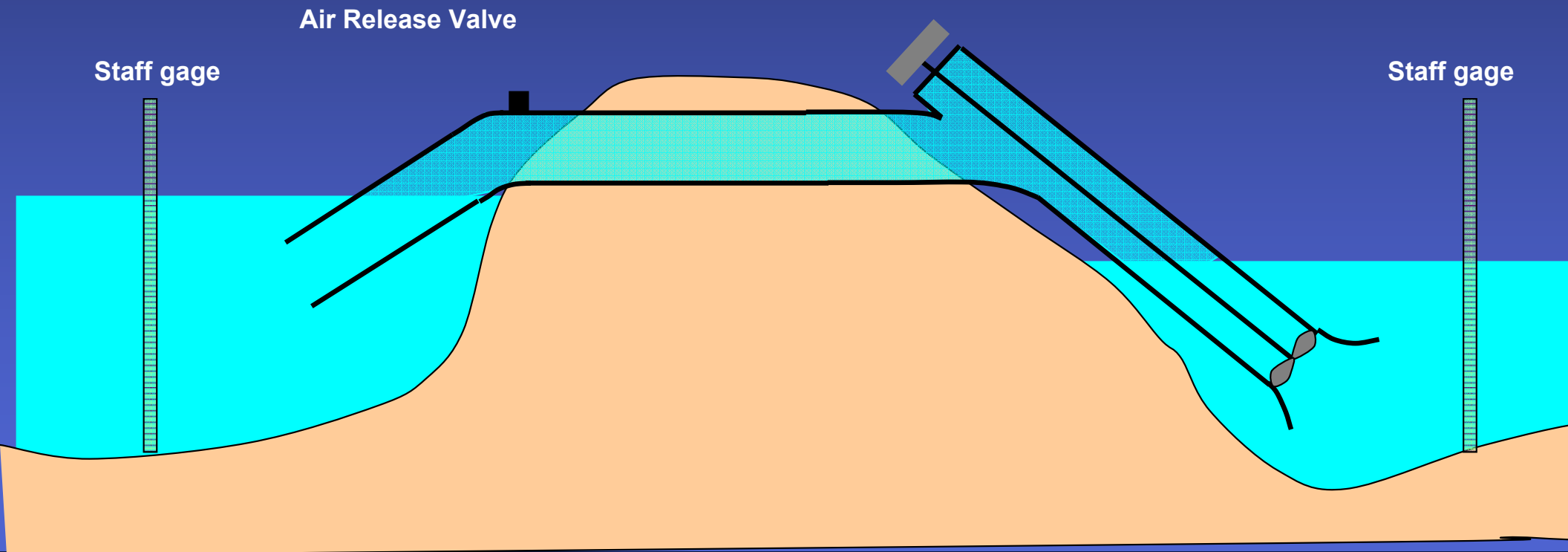
Axial Flow Pump Conduits - 2

- **Monitoring Method Selection**
  - **Candidates**
    - **Pump performance curve**
    - **Ultrasonic**

  Pump Performance Method
  - **Pros**
    - **No modifications to system**
    - **Low cost**
  - **Cons**
    - **Head, RPM, and runtime recording needed**
    - **Calibration verification tests required and complicated by site conditions, diesel engine and poor bore access**

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Axial Flow Pump Conduits - 3

Ultrasonic

- **Pros**
  - Continuous automatic flow recording
  - No head or RPM recording
- **Cons**
  - Expensive
  - Reliability questionable
  - Limited pump bore access for installation

Axial Flow Pump Conduits – 4

Pump Performance Curve Method selected because of high expense and reliability issues with ultrasonic

Equipment required:

- Up and downstream head measurement device
  - Staff gage, pressure transducers, stage recorder
- Pump RPM meter
  - Mechanical or optical, attached to engine/pump shift
- Time recording
  - Log sheet or hour meter

Axial Flow Pump Conduits - 5

Selected Secondary Measurement Devices
- Staff gages for head measurements
  - Low cost and maintenance
  - Good operator available to record data
  - Surveyed and set with same datum
  - Consistent head responses during events
- Engine Optical RPM meter
  - Reliable and easily installed
  - Pulley reduction ratio must be used with engine RPM meter
- Log sheet recording with engine hour meter backup
  - Hour meter tied to ignition and oil pressure switch
- Available manufacturers
  - See Guidebook Sections D and E

Axial Flow Pump Conduits - 6

FLOW MONITORING DATA ENTRY SHEET

FARM NAME _____

PERMIT NO. _____

SITE DESCRIPTION _____

_____

A	B	C	D	E	F	G	H	I	J	K	L
OPERATOR	PUMP ON		PUMP OFF		ENGINE	ENGINE	PUMP	UPSTREAM	DOWNSTREAM	HEAD	FLOWRATE
INITIALS	DATE	TIME	DATE	TIME	HOURMETER (HOURS)	RPM	RPM (E-RPM X .21)	STAFFGAGE READING	STAFFGAGE READING	DIFFERENCE	(USE COLUMNS H & K AND PCURVE)

Axial Flow Pump Conduits - 7

Discussion of Accuracy

    Sources of Error in Order of Importance

- **Error in pump performance curves**
- **RPM reading error, unknown variability during run**
- **Non-linear unknown stage changes between readings**
- **Runtime errors, poor records, hour meter off**
- **Error in reading stage, dirty, shifted gage**

    Good Operational Practices Can Meet Requirements

- **Perform scheduled pump calibrations at least every five years or when any changes occur**
- **Take multiple readings of stage and RPM during cycle to get a measure of variability**
- **Test RPM and hour meters periodically**
- **Keep stage gages clean and resurvey periodically**

Axial Flow Pump Conduits - 8

Pump Performance Curve Calibration/Verification

Selection of Secondary Flow Measurement Method:

- **Options:**
  - **Ultrasonic, pitot tube, streamgaging, dye fluorometry**
- **Dye fluorometry selected because pump provides good mixing, limited physical access to pump bore for ultrasonic and pitot tube methods, and less expensive than streamgaging due to availability of system**
- **Verify calibration status of fluorometer and dye injection pump**

Axial Flow Pump Conduits - 9

Pump Performance Curve Calibration/Verification

Calibration/Verification Runs

- Measure background concentration in water
- Use multiple port dye injection pipe just upstream of pump inlet
- After lift pump has been running, start dye injection pump
- Measure dye concentration just downstream of pump outlet bore until it comes to equilibrium
- Calculate flowrate using injected, background, and downstream concentrations
- Compare to existing pump performance curve, if within ± 5%, then ok, if not then additional runs are needed to update performance curves

Axial Flow Pump Conduits - 10
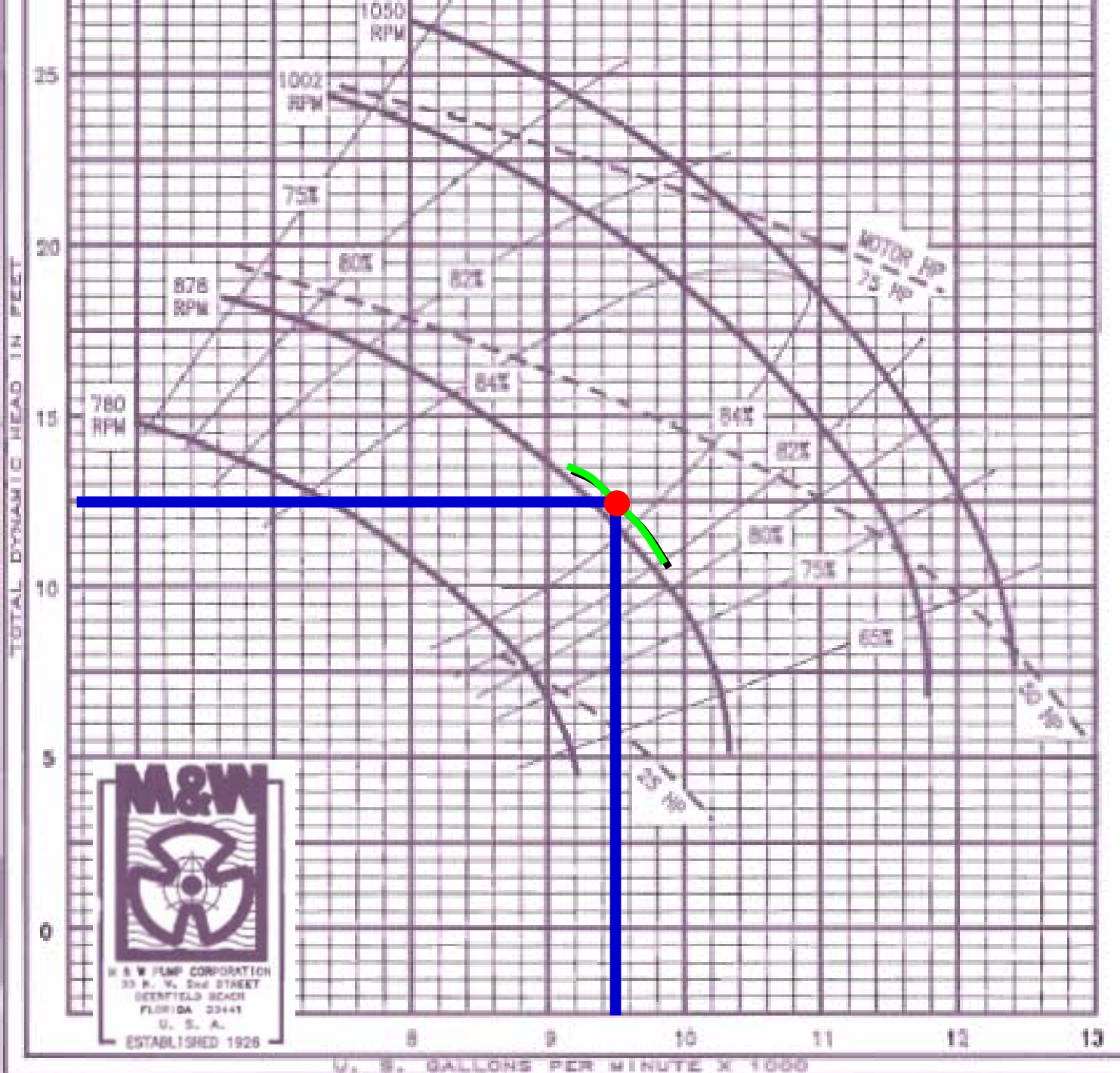
Axial Flow Pump Conduits - 11

Pump Performance Curve Calibration/Verification

If additional calibrations are indicated

- Rerun for two different pump RPM settings and for two different head differences across the pump station

- Compare to existing pump performance curves and using reasonable judgment, adjust the existing curves to match the observed data

- Note: If no pump curve is available, then the above procedure can be repeated for a minimum of three RPM settings and three head differences that represent the expected range of operation of the pump station to generate a pump curve

Open Channel Gate Control - 1

Two 3-foot gated culverts that are used to release water onto the farm from a District canal.

Staff gage

Staff gage

Datalogger

Screw Gate

Staff gage

dX

Pressure Transducer

Ballast

Pressure Transducer

sfwmd.gov
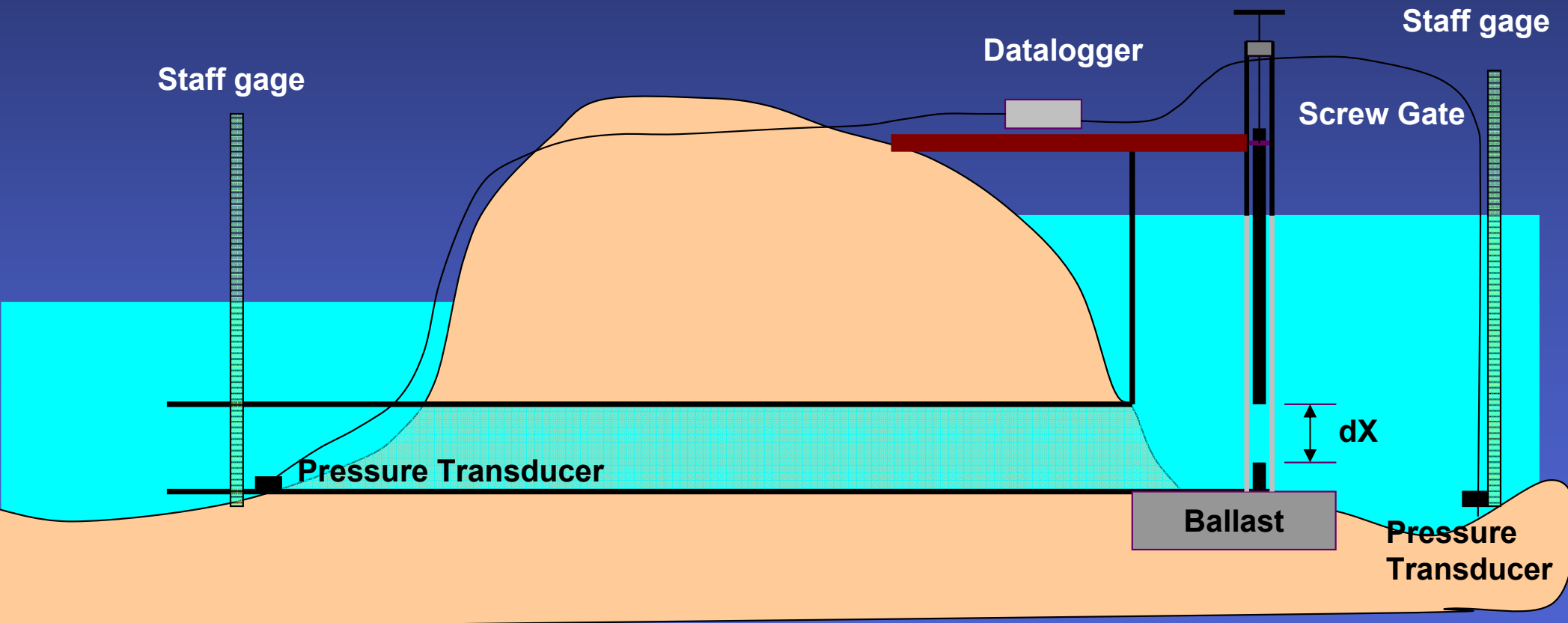
Open Channel Gate Control - 2

- **Monitoring Method Selection**
  - **Candidates**
    - **Gate equation**
    - **Ultrasonic**

  Gate Equation Method
  - **Pros**
    - **No modifications to system**
    - **Low cost**
    - **Accurate with no calibration if properly installed**
  - **Cons**
    - **Head and opening size and time recording needed**

Open Channel Gate Control - 3

Ultrasonic Method

- Pros

  - No modifications to system

  - Continuous automatic flow recording

  - No head, opening size and time recording needed

- Cons

  - Expensive

  - Reliability issues

Open Channel Gate Control - 4

Gate Equation Method selected because of high expense and reliability issues with ultrasonic

$$\text{Flow} = C_g \cdot (dX \cdot W) \cdot [(h_{up} - h_{down}) \cdot 2g]^{0.5}$$

where: C_g = gate coefficient   W = width of gate   g = gravitational constant

dX = gate opening   h = head in up and downstream sections

Equipment required:

- **Up and downstream head measurement device**
    - **Staff gage, pressure transducer, stage recorder**
- **Gate opening indicator**
    - **Mechanical gage or electronic sensor attached to gate**
- **Time recording**
    - **Log sheet or datalogger**

Open Channel Gate Control - 5

Selected Secondary Measurement Devices

- Pressure transducers with datalogger for head measurements
  - Flow equation very sensitive to heads
  - High cost, but low maintenance
  - Continuous head readings
  - Datalogger can also record gate openings
  - Transducers surveyed and set with same datum
- Gate opening sensors
  - Gate opening automatically read and flow calculated by datalogger
- Available manufacturers
  - See Guidebook Sections D and E

Open Channel Gate Control - 6

Issues on Cost, Use, and Related Accuracy

The proposed system has high capital costs, but low operator costs. Operator recording of heads and gate openings can meet accuracy requirements.

Pressure transducers, gate opening sensors, and datalogger must be tested monthly to verify proper operation – normal part of data download visit

Gate equations are valid as long as the physical integrity of the system is maintained. A calibration procedure would be needed if structure is customized

Farm Canals and Ditches - 1

Main farm canal that is used for irrigation supply and farm drainage and has no structures

District Canal

Access Road

Farm Canal

Required Measurement Point

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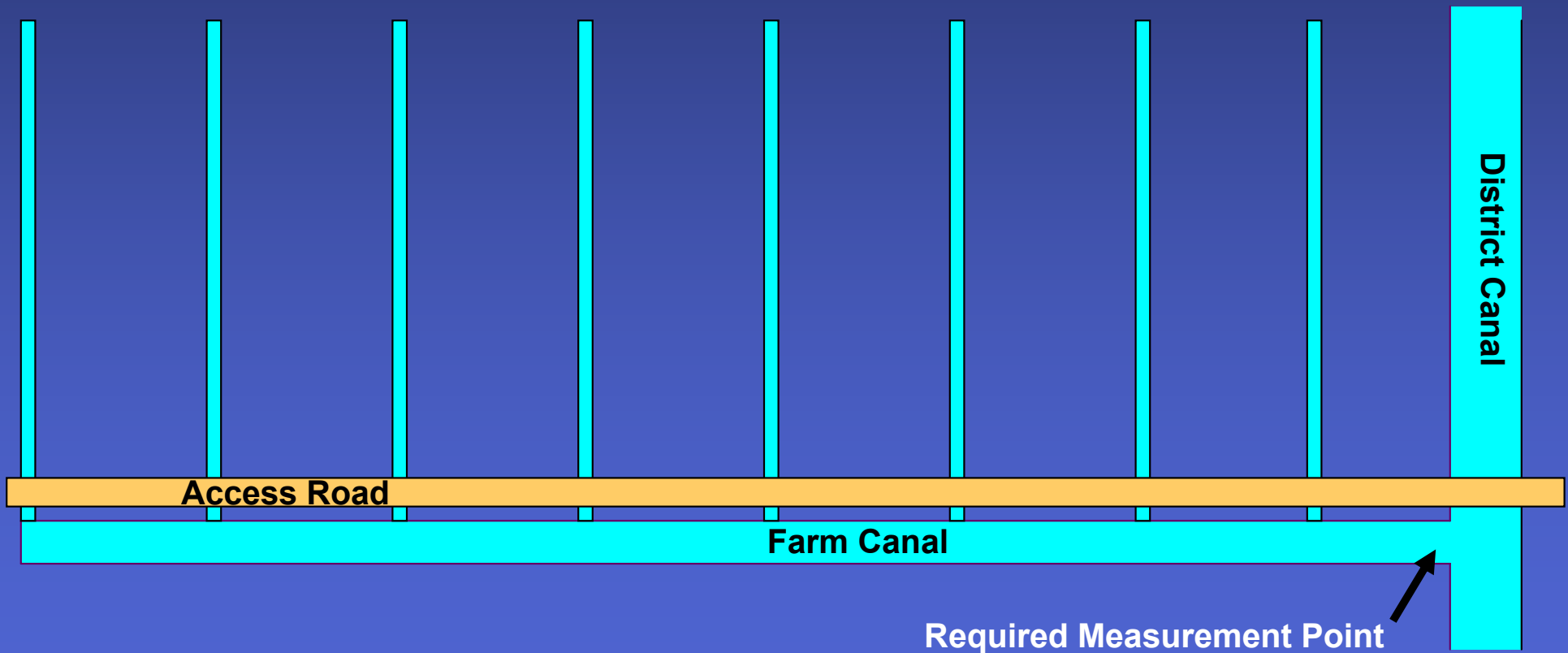
Farm Canals and Ditches - 2

- **Monitoring Method Selection**
  - **Candidates**
    - **Manning's Equation**
    - **Ultrasonic**
    - **Stream rating curve**
    - **Installation of gated culvert**
  - **Manning's Equation**
  - **Pros**
    - **Reliable theory and handles bi-directional flow**
    - **Only head measurement required after initial cross-section profiling**
  - **Cons**
    - **Very accurate head measurements required**
    - **Variable roughness coefficient and profiles**

Farm Canals and Ditches - 3

Stream Rating Curve Method
- Pros
  - Requires only one head reading
- Cons
  - Does not handle bi-directional flow
  - Inaccurate for low gradient systems

Ultrasonic Method
- Pros
  - Requires only one head reading
  - Can handle bi-directional flow
- Cons
  - Expensive, especially for full bi-directional flow
  - Mean velocity not directly measured
  - Reliability Issues

Farm Canals and Ditches - 4

Ultrasonic Method selected over Manning's and rating curve methods because of accuracy requirements and over a new gated culvert because of expense. Doppler selected over transit-time due to expense.

Equipment required:

- Doppler and pressure combo transducer and datalogger
- Staff gage for transducer verification

Available manufacturers

- See Guidebook Sections D and E

Farm Canals and Ditches - 5

Streamgaging is required to adjust doppler velocity reading since it is unlikely that a meter will cover the point of average velocity. It will also serve well for calibration

- **Doppler provides a single area measurement that will likely not represent the mean/average velocity**
  - **Two transducers recommended to address reliability issues**
- **A depth to cross-sectional area relationship required**
  - **Can be established during initial streamgaging**
- **Flow computation procedure works for bi-directional flow, however the Doppler transducer has a preferential flow direction.   The Doppler can only handle a little back flow, so a second transducer is needed for full bi-directional flow measurements**

Farm Canals and Ditches - 6

Setup for Streamgaging

- Select reach section as far away from bends and junctions as possible and determine direction of flow to be measured (can be both ways)

- Install Doppler transducer(s) at bottom, mid-stream
  - Two transducers recommended to address reliability issues
  - Anchor on concrete block attached to cables for easy installation and removal

- Install catwalk (best) or use boat to install graduated rope or cable across stream

- Use survey equipment to determine top of bank to water surface and bank elevations

- To measure water depth use graduated rod with a six inch minimum disc on its bottom

Farm Canals and Ditches - 7

Setup for Doppler System

Anchor Post

Cables

Doppler and Pressure Transducer

Concrete Anchor Block

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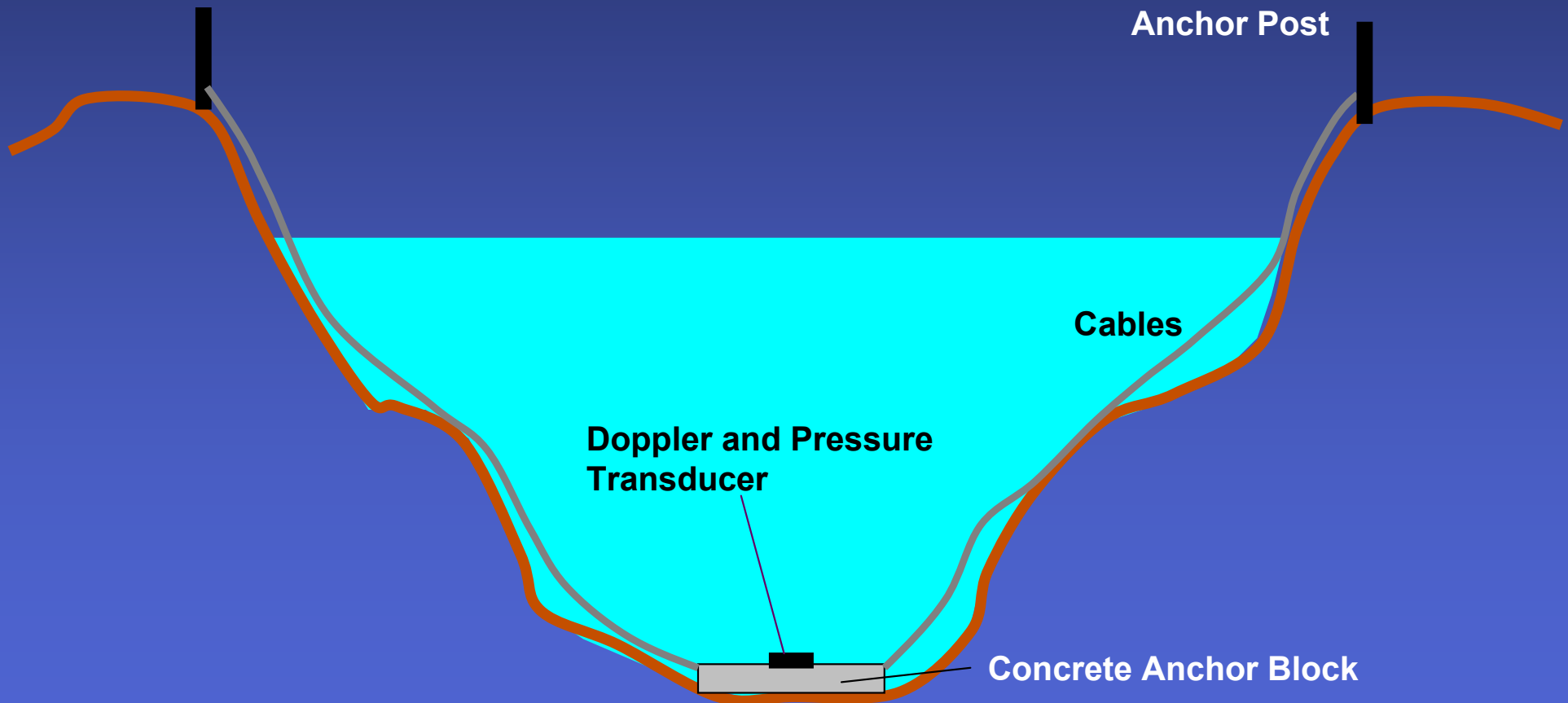
Farm Canals and Ditches - 8

Streamgaging

Step 1. Cross-sectional Profiling

**Minimum of 10 vertical sections. Use graduated rope/cable across stream.
Work from boat or catwalk. Use mechanical or electromagnetic flowmeter.**

Top of Bank Datum

dX

d_{datum}

d_1

D_{total}

d_i

Take depth reading at center of
each vertical segment

D

Canal Bottom

sfwmd.gov
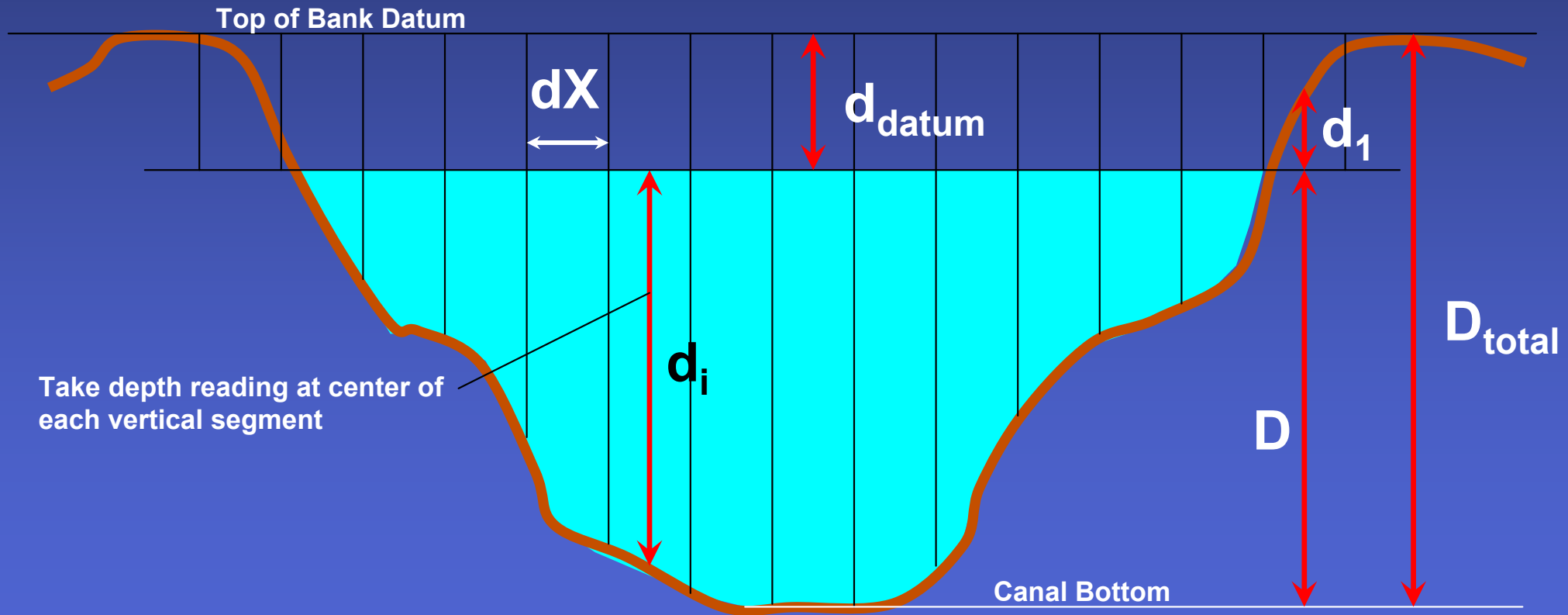
Farm Canals and Ditches - 9

Streamgaging
Step 1. Cross-sectional Profiling

$$\text{Area (D)} = \Sigma \ (D_{total} - D + d_i) \cdot dX$$

Area = $1.1038d^2 + 4.4118d$
$R^2 = 0.9997$
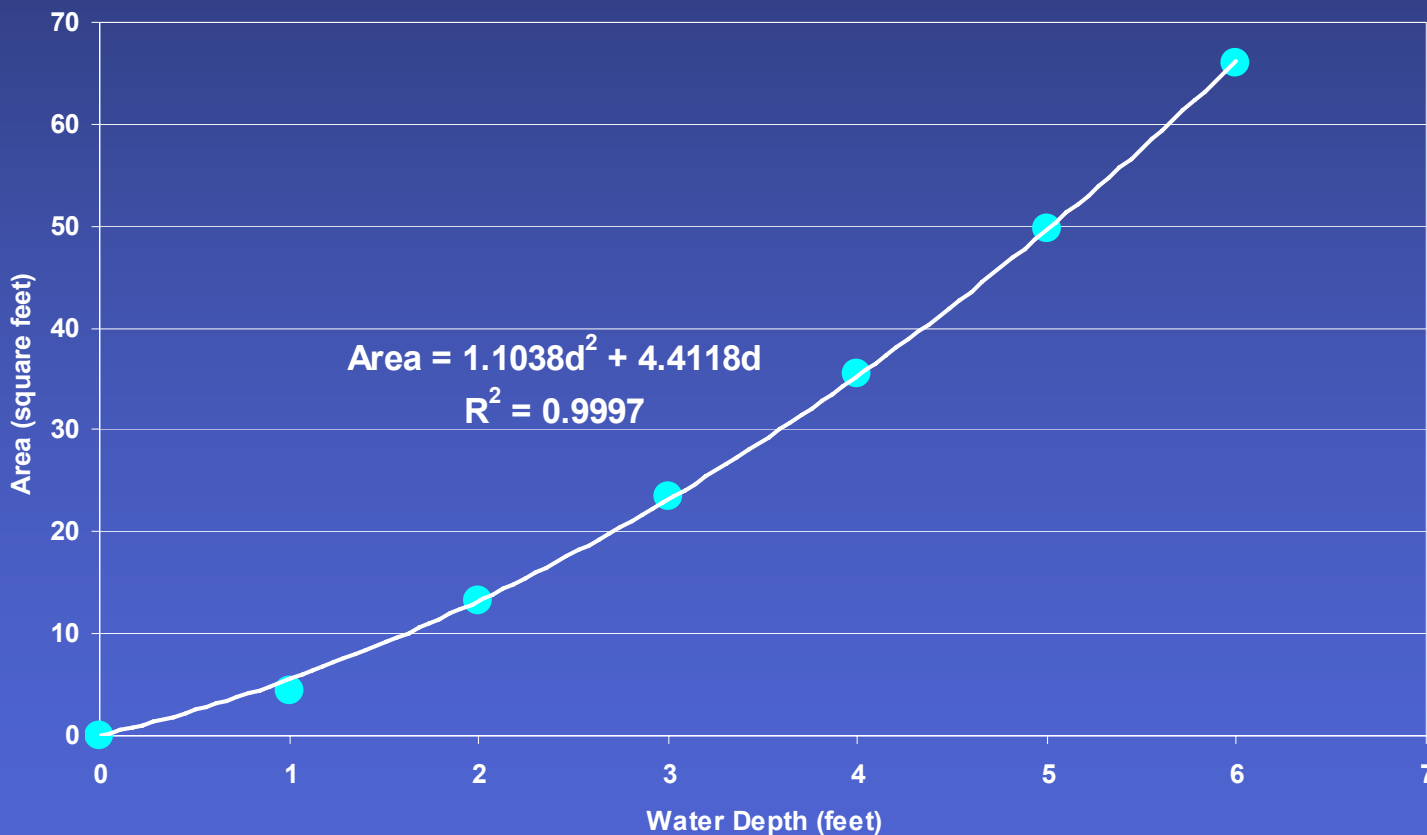
Farm Canals and Ditches - 10

Streamgaging
Step 2. Velocity Profiling
Minimum of 10 vertical sections, use graduated rope/cable across stream
Work from boat or catwalk

Mean Velocity = $\Sigma\ d_i \bullet (V_{0.2i} + V_{0.8i}) / 2 \bullet dX / Area(D)$

dX

d_i

Take velocity @ 0.2d and 0.8d
or .6d if < 2 feet

D
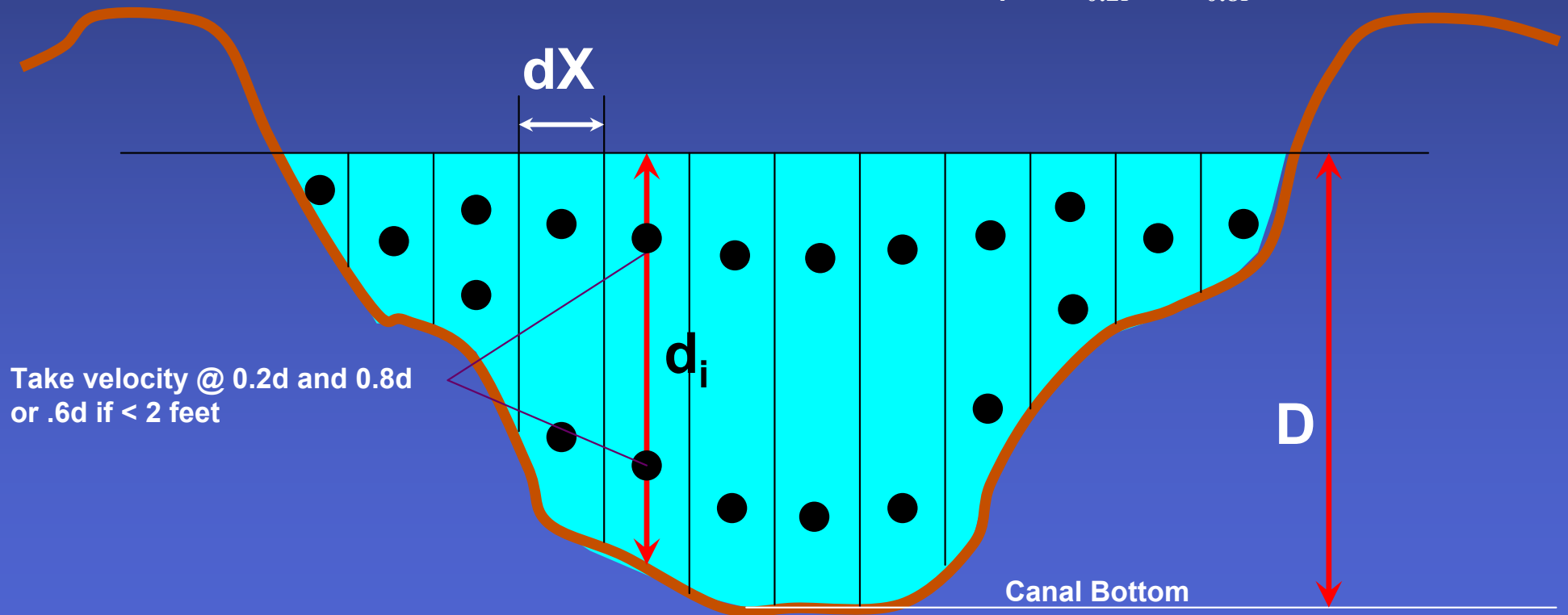
Canal Bottom

Farm Canals and Ditches - 11

A	B	C	D	E	F	G	H	I
VERTICAL CELL ID	DEPTH (FT) SURFACE TO BOTTOM	WIDTH (FT)	VELOCITY (FT/SEC)			MEAN VELOCITY Col. D or Avg D&E	AREA (FT²) B x C	MEAN FLOW (CFS) G x H
			if<2' 0.6 d	if > 2' 0.2 d	0.8 d			
1	0.9	2	0.2			0.2	1.8	0.36
2	1.8	2	0.27			0.27	3.6	0.972
3	4	2		1.1	1	1.05	8	8.4
4	7	2		1.9	1.7	1.8	14	25.2
5	10	2		2.3	2	2.15	20	43
6	11	2		2.7	2	2.35	22	51.7
7	10	2		2	1.9	1.95	20	39
8	7	2		1.7	1.3	1.5	14	21
9	3.5	2		1.5	1.1	1.3	7	9.1
10	3	2		1	0.5	0.75	6	4.5
11	1.9	2	0.21			0.21	3.8	0.798
12	1	2	0.1			0.1	2	0.2

Doppler Velocity   =   2.10   FT/SEC

Mean Velocity   =   1.67   FT/SEC

Adjustment Factor =   0.796   Converts Doppler Velocity to canal mean velocity

Streamgaging

- **Flow Calculation Procedure**
    - **Log Doppler velocity**
    - **Log depth**
    - **Calculate cross-section area for depth using depth to area relationship**
    - **Multiply Doppler velocity by adjustment factor to obtain mean velocity**
    - **Multiply mean velocity by cross-sectional area to obtain flow**

Farm Canals and Ditches - 14

Issues on Cost, Use, and Related Accuracy

Streamgaging and open channel flow measurements are very difficult to do while maintaining good accuracy. Therefore, using quality equipment is important, but will be more costly upfront.

Pressure transducer and Doppler transducers must be checked at least monthly to verify proper operation – normal part of data download visit

Any physical changes to stream profile will require recalibration (streamgaging)

Accuracies of ± 10% can be obtained if properly maintained and operated

Wrap Up

- The information presented is not all inclusive. The user is encouraged to study Sections A and C to gain a fuller understanding of flow monitoring and verification methods

- Any method used is only as good as the operator's application of the method. Hence, a less accurate method could provide better measurements than the best method.

- Use quality equipment

- Attention to detail, including maintenance and record keeping is critical

- Use qualified system designers and calibrators

Wrap Up

- The information presented is not all inclusive. The user is encouraged to study Sections A and C to gain a fuller understanding of flow monitoring and verification methods

- Any method used is only as good as the operator's application of the method. Hence, a less accurate method could provide better measurements than the best method.

- Use quality equipment

- Attention to detail, including maintenance and record keeping is critical

- Use qualified system designers and calibrators

SECTION C

**Flow Verification (Calibration) Methods for
Water Use Accounting and Reporting of
Agricultural and Other Water Uses
In South Florida**

SECTION C

FLOW VERIFICATION (CALIBRATION) METHODS FOR WATER USE ACCOUNTING AND REPORTING OF AGRICULTURAL AND OTHER WATER USE IN SOUTH FLORIDA

INTRODUCTION

This section of the handbook is intended to assist all water users with practical flow monitoring procedures that can provide results within the expected +/-10% accuracy level required by the South Florida Water Management District (SFWMD). Its content is based on the draft "Methods for Calibrating, Measuring and Reporting Agricultural Water Use in South Florida", developed by the Agricultural Coalition of South Florida, Clewiston, Florida 2005. The document lists various methods that are applicable to water use flow verification (calibration), for different withdrawal facilities.

If needed, the user is directed to Section B for more details about the methods mentioned herein. It is recognized that there are other methods discussed in this handbook and elsewhere. Although some of those methods may be more accurate than the ones discussed in this section, they may or may not be practical to use in South Florida.

While all the flow verification methods listed in this section can provide water use information acceptable to the SFWMD, method accuracy depends on the appropriate use of the method. Therefore, the SFWMD will review for approval the flow verification and resulting water use accounting and reporting information per this section, contingent upon the following conditions:

<u>Choosing the correct flow verification (calibration) method</u>:

- The methods should be suitable for the specific facility type and flow conditions to which they apply. For example, "California open pipe discharge method" can be used specifically for open pipes but should not be used for open ditches, while the "volumetric flow meter" method should be used only for small flows.

- **A "Flow Verification (Calibration) Method Selection" document is shown in Appendix "A", to aide the user in the selection of the appropriate flow verification method.**

Having the appropriate training or expertise to conduct the flow verification:

- The flow verification methods shown in this section can be performed by any user, if they have the necessary level of training or expertise. Other methods, which require a complex flow verification devices or methods, will need to be performed and documented by a Florida registered Professional Engineer.

- **If the flow verification form (shown in Appendix "B") is not complete, or is incorrectly filled or used by the individual performing the flow verification, he/she will be required to attend a flow verification training class and/or repeat the flow verification appropriately.**

Documenting the conditions during the flow verification:

- Each flow verification method in this section has a "required conditions" and "test procedure" section, followed by an example for that method. The conditions for the flow verification method chosen are the minimum conditions and should be satisfied prior to conducting the flow verification. A detailed record of these conditions and any other conditions affecting the flow test should be documented and submitted to the SFWMD, along with the flow verification method form. Field notes, pictures, scaled drawings, and/or diagrams are good ways to document all such conditions.

- **A "Flow Verification (Calibration) Method Selection" document is shown in Appendix "A", to aide the user in the selection of the appropriate flow verification method, for the condition(s) being encountered.**

Submitting the appropriate flow verification form:

- Flow verification forms are available in Appendix "B" of this Section. Each flow verification method in this section has a corresponding flow verification form. Submittal of such form to the SFWMD is mandatory.

- **If the flow verification form (shown in Appendix "B") is not complete, incorrectly filled or used by the individual performing the flow verification, he/she will be required to attend a flow verification training class and/or repeat the flow verification appropriately.**

Performing the flow verification during the dry season:

- Water use information is critical during the dry season; therefore, the flow verification should be done during the dry season. **Such dry season shall be defined as the groundwater elevation or upstream/downstream water levels present between January 1st and June 1st of any year with normal rainfall.** It is recognized that this dry season flow verification

produces water use accounting information that should be within the accuracy prescribed in the SFWMD rule, when averaged over a 12-month period.

- There are regional areas where the dry season water stages are highly variable. The level of the groundwater table or the difference in head/tail water might vary up to several feet. In such circumstances, the withdrawal facility should be calibrated for several characteristic water stage conditions and the average of these calibrations will be considered as the representative flow rate.

- The procedures described above are for a typical dry season condition in a typical calendar year. Should the water source be impacted by extreme drought conditions the SFWMD may request the user to perform additional flow verifications that more closely represent these extreme conditions, or the user may elect to do so on his/her own.

It is also recognized that some of the methods described may require modification for specific withdrawal locations and user practices. Further, procedures, calculations and tabulated flow calculation aids can vary since researchers often publish minor adjustments to standard practices and equations. Any modifications to the procedures discussed that are properly referenced should be approved by the SFWMD staff. Other modifications must be justified by the user and reviewed for approval by the SFWMD staff prior to implementation.

Finally, there may be circumstances where a water use structure does not conform to the standards discussed in this document, precluding the use of the methods described in this handbook. In such instances, the user should identify an alternative, reliable, repeatable water use accounting system to monitor water usage from each withdrawal facility in accordance with permit conditions. For these methods, in order to avoid pursuing techniques which do not provide the +/-10% accuracy standard, the user is advised to consult with a Florida registered P.E. and submit a flow verification plan to the SFWMD for approval of the **method**, before starting the measurement or investing in an alternative methodology. The SFWMD will review for approval the alternative flow verification and water use accounting methods plan on a case-by-case basis.

ACCEPTABLE FLOW VERIFICATION METHODS:

Typical water use withdrawal facilities from ground water sources are a well and pump system. It is acknowledged some wells are free flowing and may not utilize a pump. Most pumped systems typically utilize either a submersible turbine type pump or a surface-mounted centrifugal or axial flow type pump.

However, it is important here to note that flow wells in Martin and St. Lucie counties will require the verification of flow from these wells **prior to any pump installation**. Failure to provide the SFWMD with this flow verification may require the removal of the pump at the owners expense. The permittee will be authorized to pump the flow well at or below the rate at which the well would freely flow, un-pumped, at land surface.

A surface water pump station typically consists of an axial flow pump discharging into an open canal irrigation system, or a centrifugal pump discharging into a pressurized irrigation system. Some of the larger surface water irrigation systems consist of a combination of a large axial flow pump supplying irrigation water via an open canal that routes this water to internal smaller irrigation pump(s). Verifying the flow of these smaller internal irrigation pumps can sometimes be more cost effective, accurate, and easier than verifying the flow of the single large axial flow pump that supplies them water. Therefore, the user has the option to either verify the flow, account for the water used, and report the total water used from each of the smaller internal irrigation pumps, or verify the flow, account for the water used, and report the total water used from the large axial flow pump. Pump curve relationships are acceptable tools as long as the curves are certified by the manufacturer and the pump has been installed within manufacturer specifications and been in operation for less than five years. It is also acceptable to use pump curves if pumps have been rebuilt to the manufacturers certified specifications, or have had certified flow verifications (recalibrations) conducted according to the SFWMD requirements, within the last five years.

Gravity intake systems are utilized when a surface water source is held at stages higher than the water in the adjacent lands that are to be irrigated. Typically these gravity intake systems utilize a control structure with a flash board riser to control the inflow, and allow the user to open and close the system. The other typical installation is a siphon system through a pump.

Following is an alphabetical listing and explanation of acceptable and practical methods that can be used to verify the flow of the water use withdrawal facilities shown in your water use permit. Each method is followed by an example calculation. The flow verification form for each of these methods is included in Appendix "B" of this section, and will need to be filled and submitted to the SFWMD as part of this flow verification process.

CALIFORNIA METHOD

Required Conditions:

- The pipe must be level (horizontal).
- A straight length of discharge pipe must exist, which is 6 or more times the diameter in length.
- The end of the straight pipe must be cut squarely.
- The pipe must not be flowing full.
- Measurement points must be easily accessed.

Test Procedure:

- Use a carpenter's level to ensure that pipe is level in the horizontal directions.
- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Allow flow in the pipe to occur for at least 15 minutes, to obtain stable and consistent conditions (may take longer if pumping from groundwater but gap reading fluctuations and flow stream appearance should not be rapidly changing).
- The only measurements needed are the pipe inside diameter (D) and the vertical distance between the inside of the pipe and the water surface (gap) measured from the inside of the top of the pipe. Refer to distance "a" in the figure in the example below.
- Repeat the measurements at least 3 times. Calculate the average of the gap measurements.
- Flow is then calculated using the equation shown below.

<u>General Permit Information Required:</u>

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Example Flow Verification Information, Data and Calculations:

Pipe inside diameter (D) = 4 inches
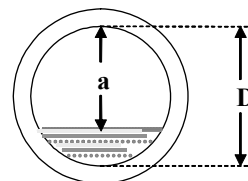
Length of level horizontal discharge pipe tested: _____

Gap Readings, (a) inches   2.5   2.0   1.5   Ave = 2.0

Flow (Q) in Pipe (cubic feet per second, cfs):

$$Q = 8.69 \times (1 - a/D)^{1.88} \times D^{2.48}$$

a = 2 inches/12 inches/foot
a = 0.165 feet
d = 4 inches/12 inches/foot
d = 0.33 feet
$Q = 8.69 \times (1 - 0.165/0.33)^{1.88} \times 0.33^{2.48}$
Q = 0.15 cfs
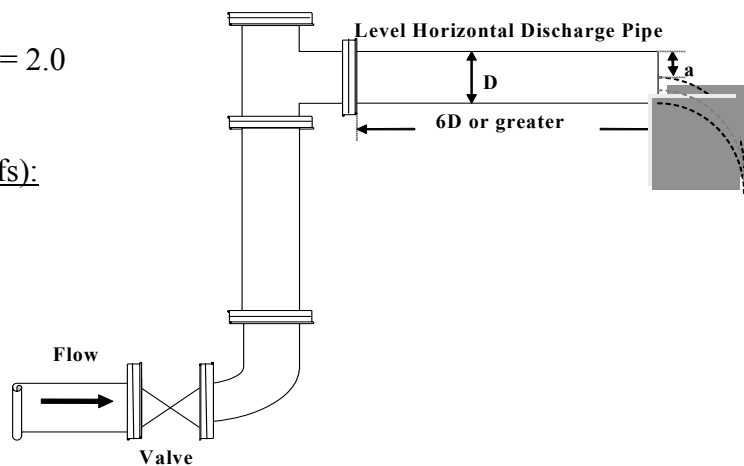
Convert Flow in Pipe to Gallons per Minute (gpm) if Desired:

Q = 0.15 cfs x 448.8 gpm/cfs
Q = 67.3 gpm

Recommended References:
United States Bureau of Reclamation. 2001. Water Measurement Manual, 3rd Edition, Revised. United States Department of the Interior. United States Government Printing Office. Washington, D.C.

ISCO, Inc. 1992. <u>Open Channel Flow Measurement Handbook</u>, 3rd Edition. ISCO, Inc. Lincoln, Nebraska.

Chapter 14 in www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm.

DOPPLER AND OTHER EXTERNAL FLOW METERS METHOD

For these instruments to function properly, pipe vibrations will need to be at a minimum. If vibrations cause undue fluctuations in readings and malfunctioning of the meter, select another method.

Required Conditions:

- Acceptable length of straight pipe away from pump or bends per manufacturer's specifications (generally 6 to 10 pipe diameters).
- Pipe is exposed and accessible.
- Pipe must flow full at point of measurement (the pipes of a pressurized irrigation system have full flow conditions).

Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Take at least 5 discrete velocity readings.
- Average the 5 velocity measurements.
- If your readings are in feet per second, multiply them by the circular area of the pipe in which you took the readings to calculate flow in cubic feet per second.
- Convert flow to gallons per minute.

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Example Flow Verification Information, Data and Calculations:

Instrument Readings:

TIME	VELOCITY READING (ft/s)
1:00 pm	8.56
1:01 pm	8.55
1:02 pm	8.57
1:03 pm	8.57
1:04 pm	8.55

Average Velocity (V) = 8.56 ft/s

Pipe inside diameter (D): 24 inches (2 ft)

Cross-Sectional Area of Pipe, A (ft^2):

$A = (\pi \times D^2)/4$ (full pipe)
$A = (\pi \times 2^2)/4$
$A = 3.14$ ft^2

Average Flow in Pipe (ft^3/s):

Q = Average Velocity x Cross-Sectional Area of Pipe
$Q = 8.56$ ft/s $\times 3.14$ ft^2
$Q = 26.88$ ft^3/s

Conversion to Gallons per Minute (gpm):

$Q = 26.88$ ft^3/s x 448.8 gpm/cfs
$Q = 12,063$ gpm

Recommended References:

Chapters 11 and 14 in www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm.

DYE FLUOROMETRY OR CHEMICAL GAUGING METHOD

This method is based on the injection of non-toxic dye or other chemical of a known concentration at a constant rate into a pipe or canal flowing with water. Assuming thorough mixing, the dye or chemical concentration can be assessed and the flow rate in the canal or pipe can be calculated based on the known chemical concentration and velocity.

Required Conditions:

- This method requires specialized equipment and expertise and will generally require a Professional Engineer (P.E.).
- Contact the SFWMD or the Florida Section of the American Society of Agricultural and Biological Engineers (ASABE) for a listing of P.E.'s available to run this test for you.

Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- This method requires specialized equipment and expertise and will generally require professional assistance.
- Contact the SFWMD or the Florida Section of the American Society of Agricultural and Biological Engineers, for a listing of professionals available to assist you with this method.
- See Section B for discussion about dye fluorometry methods.

Recommended References:

Chapter 12 in www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm.

DYE TRACER OR COLOR METHOD

This method is based on the batch (slug) injection of a small amount of bright non-toxic dye or colorant into a canal or pipe flowing with water. The time required for the dye to travel from one location to another location in the same canal or pipe is measured. The volume of water contained in the canal or pipe between these two locations, divided by the travel time, is used to determine the flow rate in the canal or pipe.

Required Conditions:

- Flow within the channel or pipe must have known or measurable dimensions (depth, width and length). This will not be a problem in pipes but will require suitably accurate channel measurements for canals or ditches.
- Flow in the canal or pipe must be steady and constant during the calibration measurements (steady flow in open channels is defined as flow occurring with no changes in depth).
- Must have access to the dye injection point.
- Must be able to see the discharge point and observe color change in the flow stream.
- Injection device should deliver the slug of dye perpendicular to the flow stream with little or no initial velocity in the upstream or downstream directions.
- Injection device should deliver the slug of dye near the area of mean velocity within the flow stream. For open channels, injection should occur generally at a point located 6/10 of the total depth of the stream from the water surface. For closed pipes, the injection point location should take place at a distance ranging from 15% to 29% of the pipe diameter in from the pipe wall. For best measurement accuracy, see Sections B, Basic Principles of Flow Monitoring and System Selection, and Section C, Teaching Module 1.
- Injection device should have a positive shutoff at the tip so there will be no leakage of dye after the dye injection has occurred.

Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.

Case 1. Canal or Pipe with Uniform Geometry

- Determine the pipe or canal water flow area, A (ft^2).
- Measure the distance from the injection point to the observation point, D (ft).
- Instantaneously trigger the injection device and stopwatch.
- Stop the stopwatch when the color change is observed; record the time, T (seconds).

Repeat the above two steps at least two more times.
- Average the three measurements.
- Divide D by T to obtain the velocity, V (ft/sec).
- Multiply V by A to obtain the flow, Q (ft^3/sec).
- Multiply Q by 448.8 to obtain the flow in gallons per minute (gpm).

Case 2. Variable Canal or Pipe Geometry

- Determine the pipe or canal cross-sectional area of water flow, A1, A2, A3, etc. (ft^2) for each uniform segment of pipe or channel, between the injection point and the observation point.
- Measure the length of each segment, L1, L2, L3, etc. (ft).
- Multiply each segment length by the corresponding segment cross-sectional area to obtain the volume (V1, V2, V3) of each segment.
- Add up all of the segment volumes to obtain the total flow volume, V (ft^3).
- Instantaneously trigger the injection device and a stopwatch.
- Stop the stopwatch when the color change is observed and record the time, T (seconds).
- Repeat the above two steps at least two more times.
- Use the average time from the three measurements.
- Divide V by average T to obtain the flow, Q (ft^3/sec).
- Multiply Q by 448.8 to obtain the flow in gallons per minute (gpm).

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____ __
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Example Flow Verification Information, Data and Calculations:

Uniform Canal Section Used (assumed trapezoidal shape):
- (a) Bottom width: 5 ft
- (b) Width at water surface: 15 ft
- (c) Water depth: 2.5 ft
- Distance along canal between starting and ending points (D): 85 ft

Stopwatch Readings:

Reading	Travel Time (T) in Seconds
1	85
2	84
3	86
AVERAGE	**85**

Average Water Velocity in the Canal (V), in Feet per Second:

V = 85 ft canal section length/85 seconds average travel time
V = 1 ft/s

Canal Water Flow Area (A) in Square Feet:

A = (a + b) x c/2
A = (5 ft + 15 ft) x 2.5 ft/2
A = 25 ft^2

Average Flow in the Canal (Q), in Cubic Feet per Second:

Q = Canal Water Flow Area x Average Water Velocity in the canal
Q = 25 ft^2 x 1 ft/s
Q = 25 cubic feet per second (ft^3/s or cfs)

Average Flow in the Canal (Q), in Gallons per Minute (gpm):

Q = 25 ft^3/s x 448.8 gpm/cfs
Q = 11,220 gpm

Important Note: Refer to Section A and Section B, Teaching Module 2 for assistance in determining the water flow area in canals that are not easy to identify.

Recommended References:

Chapter 12 in www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm.

ELECTROMAGNETIC INSERTION AND NON-INSERTION METERS METHOD

This method is based on the utilization of a factory calibrated flow meter, which derives flow measurements in pipes or canals from the voltage induced in a specially designed magnetic probe or sensor. The induced voltage is measured and converted to a velocity reading by the flow meter display device. Periodic recalibration of the flow meter by the factory or other qualified personnel is necessary.

Required Conditions:

- Flow within the canal or pipe must have known or measurable dimensions to determine cross-sectional area of flow (diameter, depth, width and length).
- Flow in the canal or pipe must be steady (water surface level must not be changing) and constant during the calibration measurements.
- Must have access to the measurement point.
- Select measurement point based on ease of access, full pipe flow (which is preferred over partial pipe flow) and recommended distance downstream of elbows, pumps, transitions or other flow disturbances (generally 6 to 10 pipe diameters depending on flow characteristics).
- Must be able to hold or fasten the probe perpendicular to the flow direction.
- Probe mounting or rod must be rigid enough to avoid flexing and vibration (becomes important consideration at velocities over 2.5 feet per second).

Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.

Case 1. Full Pipe Flow

- Determine the pipe inside diameter, D (ft).
- Calculate the cross-sectional area of flow, A (ft^2)
- Determine if the pipe flows full under average dry season conditions.
- Install meter probe according to manufacturer's recommendations.
- Observe velocity readings over a 5 to 10 minute period to ensure stable flow (readings should not vary more than 10%). If there is variation in excess of 10%, continue to run the system until stable flow is established or you have determined the cause of the instability and resolved the cause.

- Record 10 velocity readings, V (ft/sec), over a 5 minute period.
- Average the recorded velocity readings, V (ft/sec).
- Multiply V by A to obtain the flow, Q (ft^3/sec).
- Multiply Q by 448.8 to obtain the flow in gallons per minute (gpm).

Case 2. Closed Pipe Flowing Partially Full

- Determine the cross-sectional area of flow, A (ft^2), in the pipe at the measurement point.
- Install meter probe according to manufacturer's specifications.
- Observe velocity readings over 5 to 10 minute period to ensure stable flow (readings should not vary more than 10%). If there is variation in excess of 10%, continue to run the system until stable flow is established or determine the cause of the instability and fix the cause.
- Record 10 velocity readings, V (ft/sec), over a 5 minute period.
- Average the recorded readings, V (ft/sec).
- Multiply V by A to obtain the flow, Q (ft^3/sec).
- Multiply Q by 448.8 to obtain the flow in gallons per minute (gpm).

Case 3. Canal or Ditch Flow

- Determine the cross-sectional area of flow, A (ft^2), in the ditch or canal at the point of measurement.
- Follow procedure for Case 2.

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____ __
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Example Flow Verification Information, Data and Calculations:

Case 1. Full Pipe Flow
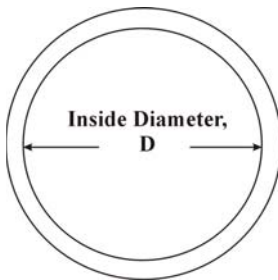
36" inside pipe diameter = 3 ft diameter (D)
Pipe is flowing full
Length of level horizontal discharge pipe tested: _____

Electromagnetic Meter Readings:
Velocity
Readings,   9.0   9.1   9.2   9.3   9.4   9.5   9.6   9.7   9.8   9.9
(ft/s)

Average Velocity = 9.45 ft/s

Cross-Sectional Area of Pipe (ft^2):

$A = (\pi \times D^2)/4$ or $(\pi \times$ pipe radius^2) where $\pi \sim 3.14$
$A = (3.14 \times 3^2)/4 = 7.07$ ft^2

Average Flow in Pipe (ft^3/s):

Q = Velocity in Pipe x Cross-sectional Area of Pipe
Q = 9.45 ft/s $\times$ 7.07 ft^2 = 66.81 ft^3/s

Conversion to Gallons per Minute (gpm):

$Q = 66.81$ ft^3/s x 448.8 gpm/cfs = 29,985 gpm

Case 2. Partial Pipe Flow

36" diameter pipe = 3 ft. diameter (D)
Pipe is flowing half full (depth of water in pipe = 1.5 ft.)
Length of level horizontal discharge pipe tested: _____

Electromagnetic Meter Readings:
Velocity
Readings,   9.0   9.1   9.2   9.3   9.4   9.5   9.6   9.7   9.8   9.9
(ft/s)

Average Velocity = 9.45 ft/s

Cross-Sectional Area of Water Flow in Pipe, A_{part} (ft^2):

$A = (\pi \times D^2)/4$ (full pipe)
$A = (\pi \times 3^2)/4$
$A = 7.07$ ft^2

$A_{part} = A/2$
$A_{part} = 7.07$ ft^2/2
$A_{part} = 3.54$ ft^2

Important Note: Refer to Appendix C in this Section or geometry handbooks, for assistance in
                determining the water flow area in pipes that are not flowing full or half full.

Average Flow in Pipe (ft^3/s):

Q = Average Velocity x Cross-Sectional Area of Water Flow in Pipe
$Q = 9.45$ ft/s $\times$ 3.54 ft^2
$Q = 33.40$ ft^3/s

Conversion to Gallons per Minute (gpm):

$Q = 33.40$ ft^3/s x 448.8 gpm/cfs
$Q = 14,990$ gpm

Case 3. Canal or Ditch Flow

Canal Section Used (assumed trapezoidal shape):
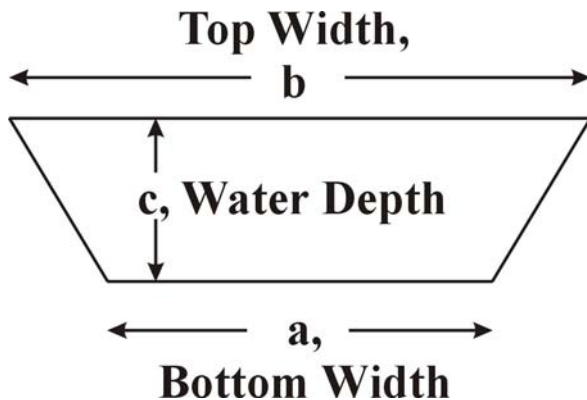
- (a) Bottom width: 5 ft
- (b) Width at water surface: 15 ft
- (c) Water depth: 2.5 ft

Electromagnetic Meter Readings:
Velocity
Readings,   0.5   0.6   0.7   0.8   0.9   1.0   1.1   1.2   1.3   1.4
(ft/s)

Average Velocity = 0.95 ft/s

Canal Water Flow Area (A) in Square Feet:

$A = (a + b) \times c/2$
$A = (5 \text{ ft} + 15 \text{ ft}) \times 2.5 \text{ ft}/2$
$A = 25 \text{ ft}^2$

Average Flow in the Canal (Q) in Cubic Feet per Second:

Q = Canal Water Flow Area x Average Water Velocity in the canal
$Q = 25 \text{ ft}^2 \times 0.95 \text{ ft/s}$
$Q = 23.75$ cubic feet per second (ft^3/s or cfs)

Average Flow in the Canal (Q) in Gallons per Minute (gpm):

$Q = 23.75 \text{ ft}^3/\text{s} \times 448.8 \text{ gpm/cfs}$
$Q = 10,659 \text{ gpm}$

Important Note: Refer to Section A or Section B, Teaching Module 2 for assistance in determining the water flow area in open channels (streamgauging methods) that are not easy to identify.

Recommended References:

Chapter 10 in www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm.

Chapter 14 in www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm.

www.1728.com/circsect.htm. Calculator for area of circle segment.

FLOAT VELOCITY METHOD

Required Conditions:

- This method should be selected as a last resort for flow verification. If possible, other methods listed in this Section should be used.
- The section of channel/ditch chosen to do the measurement only carries water from <u>one</u> pump permitted by SFWMD and is located as close to the pump as possible without violating the following conditions.
- There are no other ditches branching out from the ditch chosen, between the irrigation pump being calibrated and the ditch measurement location.
- There is a straight section of ditch at the location where the measurement will be done so that a floating device can travel for at least 20 seconds.
- Ditch has the same dimensions (depth, width, bank slope), throughout the section of ditch chosen for measurement.
- Ditch does not have excessive vegetative growth or debris that will have major impacts on the flow stream below the water surface throughout the section of ditch chosen for measurement (a good rule of thumb is that the vegetation be no taller than 6 inches for a typical ditch flowing at or near capacity.
- Water flow in the ditch is smooth and consistent (not turbulent and no eddies), throughout the section of ditch chosen for measurement.
- The depth of water in the ditch is at least 1 foot, throughout the section of ditch chosen for measurement.
- Floating devices must have a clear and straight pathway
- Taking measurements on excessively windy days, or when winds are in the direction of flow, should be avoided.

Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Mark starting point and ending point along the ditch, and measure the distance between the two points.
- Measure and record the following ditch information between the starting point and ending point:
    - Water depth
    - Width at the water surface
    - Bottom width.
    - If desired, greater accuracy can be attained through use of area determination methods used in streamgauging techniques.

- Use similar size and weight floats.
- Select the number of floats to use (see table below) and label or number each float.
- Evenly place the floats across the width of the ditch (at least 5 feet apart), at a location at least 3 feet before the starting point.
- Record the time it takes each float to go from the starting point to the ending point, along the chosen section of ditch.
- Repeat the above two steps at least two more times. Use the average of the measurements.

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____ __
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Example Flow Verification Information, Data and Calculations:

- Ditch Section Used (assumed trapezoidal cross-section):
  - (a) Bottom width: 5 ft
  - (b) Width at water surface: 15 ft
  - (c) Water depth: 2.5 ft
  - (D) Distance along ditch between starting and ending points: 100 ft

- Number of Floats used (from table below): 2

Ditch Width at Water Surface (ft)	Number of Floats
0 - 10	1
10 - 15	2
15 - 20	3
20 - 25	4

Note: For ditches wider than 15 ft. use the numbers of floats indicated in the table above and add the corresponding numbers of floats and rows for Run 1 through Run 3.

- Float Readings:

Run 1

Float Number	Travel Time (T, Seconds)
1	82
2	88
AVERAGE	85

Run 2

Float Number	Travel Time (T, Seconds)
1	80
2	88
AVERAGE	84

Run 3

Float Number	Travel Time (T, Seconds)
1	85
2	87
AVERAGE	86

Average Travel Time for All Floats and All Runs:

T = (85 + 84 + 86)/3 = 85 seconds

Average Water Velocity in the Ditch (Feet per Second):

V = 0.85 x D ft/T seconds
    where 0.85 is a constant that adjusts surface velocity to average channel velocity, D is the test travel distance and T is the time to travel the test distance.

V = 0.85 x 100 ft/85 seconds

V = 1 ft/s

Cross-Sectional Area of Channel Section Used for Test:

A = (a + b) x c/2
A = (5 ft + 15 ft) x 2.5 ft/2
A = 25 ft^2

Average Flow in the Ditch (ft^3/s):

Q = V x A
Q = 1 ft/s x 25 ft^2
Q = 25 ft^3/s

Conversion to Gallons per Minute (gpm):

Q = 25 ft^3/s x 448.8 gpm/fps
Q = 11,220 gpm

Important Note: Refer to Section A or Section B, Teaching Module 2 for assistance in determining the water flow area in canals (streamgauging methods) that are not easy to identify.

Recommended References:

Chapter 13 in www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm.

FLOW PROBE METER METHOD

Required Conditions:

- Partially full or full pipe flow is occurring from structures such as culverts or surface water pump discharge pipes.
- Flow must not contain excessive debris.
- Must have access to end of discharge pipe.
- Eddies and flow direction changes must not be occurring at the discharge/measuring point.

Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Determine the inside diameter of the pipe in the same unit of measure as your Flow Probe reads (i.e. use feet if your meter reads feet per second).
- Make sure the water has been flowing long enough to obtain a normal and stabilized condition.
- Position the flow probe at or slightly in the end of the pipe, and measure the velocity at a distance away from the pipe walls that is approximately 29% of the diameter at two different locations (i.e. from the side and from the bottom if flowing full).
- If the pipe is not flowing full, measurements should be taken around the average velocity point for open channel flow (generally about 0.6 times the depth of flowing water down from the water surface in the center of the pipe).
- Repeat the measurement step above once a minute for five minutes to obtain a good average.
- Calculate the flow rate.

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____ __

(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Example Flow Verification Information, Data and Calculations:

Case 1. Full Pipe Flow

Pipe inside diameter = 35 inches = 2.92 feet

Flow Probe Measurement Locations Away From Pipe Walls:

From the bottom of the pipe= Pipe Diameter x 0.29 = 2.92 ft x 0.29 = 0.85 ft
From the side of the pipe = Pipe Diameter x 0.29 = 2.92 ft x 0.29 = 0.85 ft

Flow Probe Velocity Measurement Results:

From the bottom of the pipe: 6.3 ft per second
From the side of the pipe: 6.7 ft per second
Average Velocity (V): (6.3 + 6.7)/2 = 6.5 ft per second

Cross-Sectional Area of Pipe:

$A = \pi D^2/4$
$A = 3.14 \times 2.92^2/4$
$A = 6.69 \text{ ft}^2$

Average Flow in Pipe (ft3/s):

$Q = A \text{ (ft}^2) \times \text{Average Velocity (ft/s)}$
$Q = 6.70 \text{ ft}^2 \times 6.5 \text{ ft/s}$
$Q = 43.5 \text{ ft}^3/s$

Conversion to Gallons per Minute (gpm):

Q = 43.5 ft^3/s x 448.8 gpm/cfs = 19,523 gpm

Case 2. Pipe Flowing Partially Full

Important Note: Refer to Appendix C in this Section or a geometry handbook, for assistance in determining the water flow area in pipes that are not flowing full or half full.

Pipe inside diameter measurement = 35 inches = 2.92 feet
Flow Depth in Pipe (half full): 35 inches/2 = 17.5 inches or 1.46 feet

Cross-Sectional Area of the Pipe = πr^2 = 3.14 x (2.92/2)^2 = 6.69 ft^2

Flow Probe Measurement Locations Away From Pipe Walls:

From the bottom of the pipe = Pipe Diameter x 0.29 = 2.92 ft x 0.29 = 0.85 ft
From the side of the pipe = Pipe Diameter x 0.29 = 2.92 ft x 0.29 = 0.85 ft

Flow Probe Velocity Measurement Results:

From the bottom of the pipe: 6.3 ft per second
From the side of the pipe: 6.7 ft per second
Average Velocity (V): (6.3 + 6.7)/2 = 6.5 ft per second

Cross-Sectional Area of Pipe Flowing Half Full:

A_{part} = A/2
A = πD^2/4
A = 3.14 x 2.92^2/4
A = 6.69 ft^2
A_{part} = 6.69 ft^2/2
A_{part} = 3.35 ft^2

Average Flow in Pipe (ft^3/s):

Q = V ft/s x A_{part} ft^2
Q = 6.5 ft/s x 3.35 ft^2
Q = 21.8 ft^3/s

Conversion to Gallons per Minute (gpm):

Q = 21.8 ft^3/s x 448.8 gpm/cfs
Q = 9,784 gpm

Recommended References:

www.globalw.com
www.1728.com/circsect.htm. Calculator for area of circle segment.

ORIFICE MANOMETER METHOD

Required Conditions:

- The pipe must be flowing full.
- The pipe must be level (horizontal) with a smooth interior.
- The distance between the orifice and any valves or fittings in the approach pipe must be greater than 8 pipe diameters (4 feet is recommended).
- There should be 2 feet between the pressure tap and the orifice.
- The end of the pipe must be cut squarely.
- Measurement points must be easily accessed.
- The orifice must be a true bore, smooth, diameter accurate to +/-0.001 inches.
- The orifice material should be 1/8 inch thick and rigid.
- Refer to the figure in the example below.

Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Allow flow in the pipe to occur for at least 15 minutes to obtain stable and consistent conditions.
- When selecting the size of the orifice it is useful to estimate the pipe flow with the California Pipe Method in order to select an orifice that will produce about 20 to 30 inches of water column at the pipe's manometer.
- An air bleeder must be used to let the air out of the top of the pipe at the orifice end before measurements are taken.
- The flow is derived from measuring the orifice diameter, pipe inside diameter and the water level (H) in a standpipe (manometer) measured from the centerline of the discharge pipe located 2 feet upstream of the orifice.
- Repeat the hydraulic head measurements at least 3 times and use the average of the measurements.
- A table or graph is used to select the "C" coefficient, based on the pipe and the orifice diameters. A typical figure for selecting "C" is included in the example below. Tables and figures are available in many hydraulic handbooks.
- The orifice can be left in place if continuous monitoring is necessary.
- This method is one of the most often recommended methods for testing other metering methods for accuracy because of its simplicity and, when accurately constructed, its ability to measure within 2% of exact flow.

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____ __
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Example Flow Verification Information, Data and Calculations:
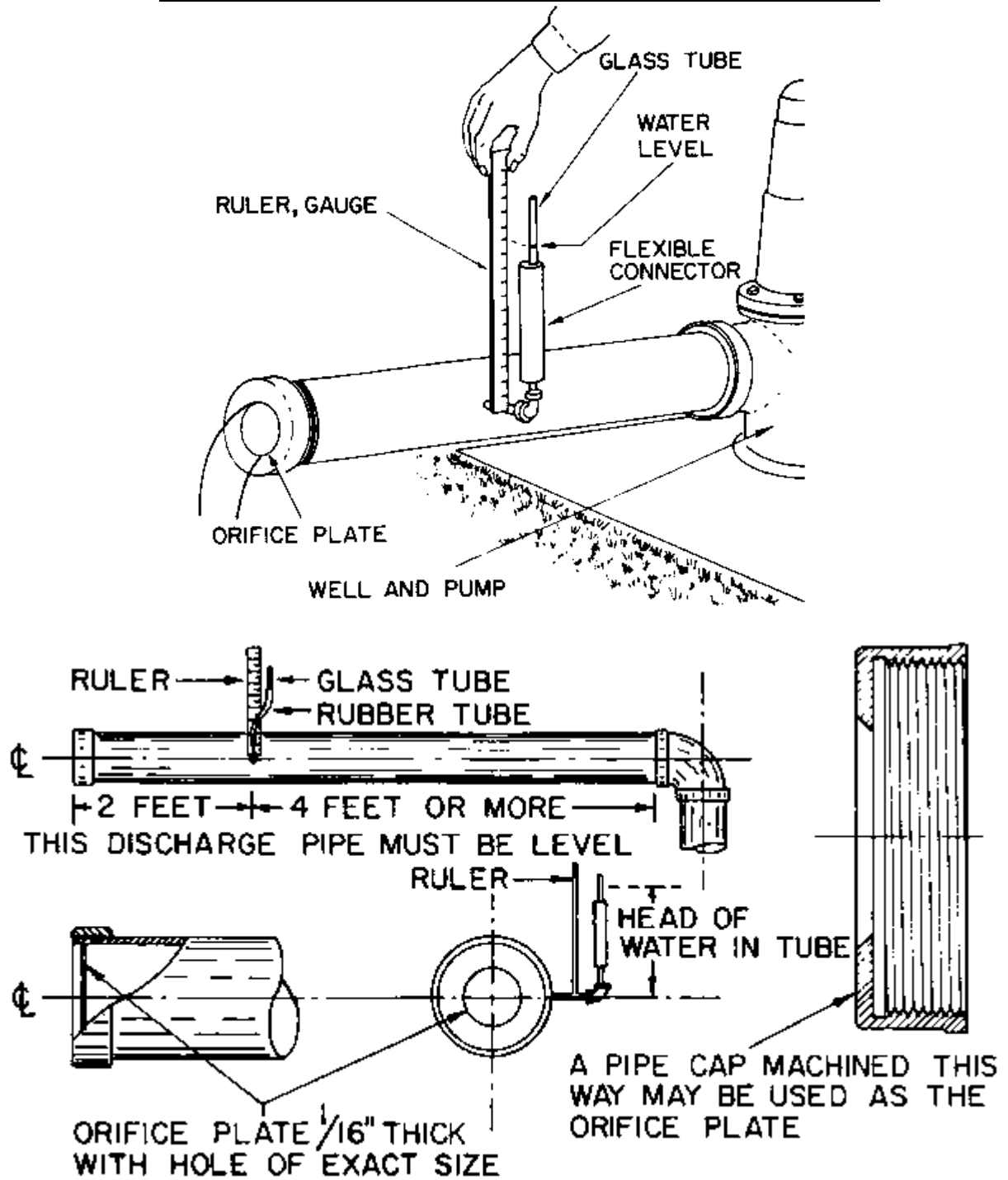
Note: Care must be taken to mount the pressure tap flush with the inside of the discharge pipe

Pipe inside diameter (D) = 4 inches

Orifice diameter (d) = 3 inches

Length of level horizontal discharge pipe tested: _____

Manometer Measurements:

Level of Water (H) in
Manometer (inches)   5.75   6.0   6.25   Avg.:6.0

Average hydraulic head (H):

H = (5.75 + 6.0 + 6.25)/3 = 6.0 inches

Coefficient (C) from graph below:

Ratio of orifice diameter to pipe diameter = 3 in/4 in = 0.75
From graph below, C = 0.71

Cross-Sectional Area (A) of Orifice (in^2):

$A = (\pi \times d^2)/4$
$A = (3.14 \times 3^2)/4$
$A = 7.07$ in^2

Flow (Q) in Pipe (gpm):

$Q = 8.02 \times C \times A \times H^{0.5}$
$Q = 8.02 \times 0.71 \times 7.07 \times 2.45$
$Q = 98.6$ gpm
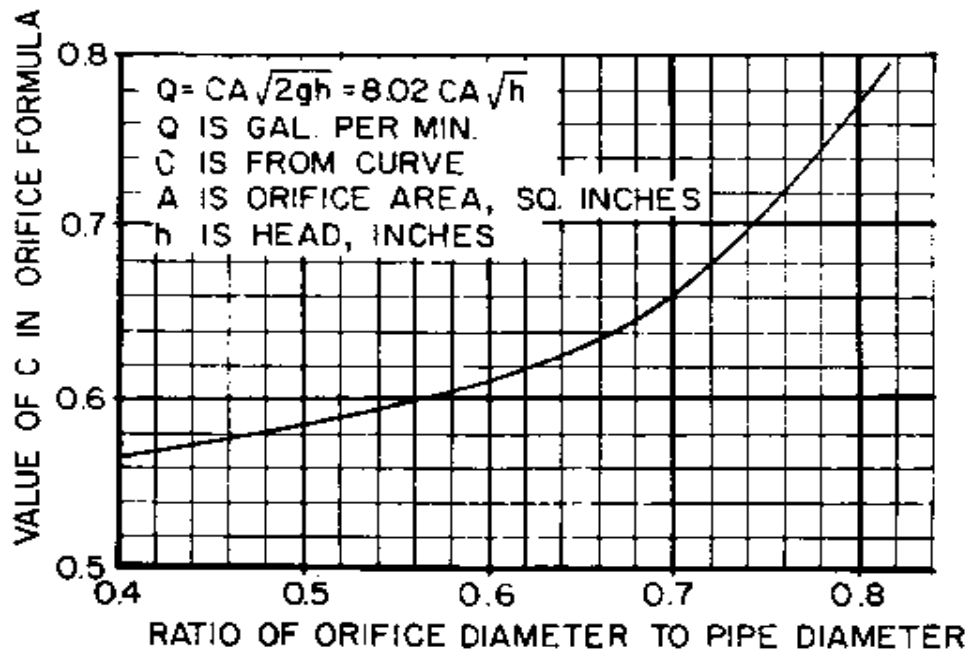
VALUE OF C IN ORIFICE FORMULA

$$Q = CA\sqrt{2gh} = 8.02\, CA\sqrt{h}$$

Q IS GAL. PER MIN.
C IS FROM CURVE
A IS ORIFICE AREA, SQ. INCHES
h IS HEAD, INCHES

RATIO OF ORIFICE DIAMETER TO PIPE DIAMETER

Recommended References:

Colt Industries, Inc. 1979. <u>Hydraulic Handbook</u>, 11th Edition. Fairbanks Morse Pump Division of Colt Industries. Kansas City, Kansas.

Smajstrla, A.G. and D.S. Haman. 1987. Orifice meters for water flow measurement. IFAS Extension Circular AE22. University of Florida Cooperative Extension Service. Gainesville, Florida.

PITOT TUBE MANOMETER METHOD

Required Conditions:

- Straight length of pipe.
- Flow profiles must be well-developed within the pipe (6 to 20 pipe diameters from pumps or pipe bends.
- Water must be fairly clean to avoid clogging and flow stream disruption.
- Pipe must be exposed and available.
- Can be used for partial or full flowing in pipes.

Test Procedures:

Case 1. Full Pipe Flow

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Take at least 10 manometer readings across the pipe cross-section (recommend use of the 10-point method discussed in Section A; more if flow is expected to be turbulent or the readings are being taken close to pipe obstructions).
- The readings consist of the difference in the height of the two water columns (H) in the manometer (if 2 separate tubes are used, simple calculations will be needed).
- Calculate the average of the readings.
- Determine the water velocity in the pipe, based on that average reading and the formula described below.
- Calculate the cross-sectional area of the pipe.
- Calculate the flow in the pipe by using the cross-sectional area of the pipe and the water velocity in the pipe.

Case 2. Partial Pipe Flow

- When conducting your test, use representative dry season conditions, as defined in "Seasonal variations in water stages" located at the beginning of the current section.
- Measure the depth of flow in the pipe. Since the pipe is of known dimensions, an accurate determination of the flow depth in the center of the pipe will allow calculation of the flow area. From the access tap, insert a measuring device and move it side to side after ensuring that it is level in the upstream to downstream direction. The maximum measurement is the vertical depth of the water profile. Repeat several times and average those measurements (chalk on the device will show wetted depth).

- Take at least 10 manometer readings (across the flow and vertically), which consist of the difference in the height of the two water columns (H) at the manometer. Read the height of the water column at the manometer and adjust for the vertical difference between the bottom of the manometer and the center of water flow in the pipe.
- Calculate the average of the abovementioned readings.
- Determine the water velocity in the pipe based on that average reading and the formula described below.
- Calculate the cross-sectional area of water flow in the pipe. See streamgauging flow area determination techniques in Sections A and B for more information.
- Calculate the flow in the pipe by multiplying the cross-sectional area of water flow in the pipe by the water velocity in the pipe.

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____ __
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Example Flow Verification Information, Data and Calculations:

Case 1. Full Pipe Flow

48" diameter pipe = 4 ft.

Manometer Readings, H (inches)	16.9	17.3	17.0	16.7	17.5	17.7	17.6	17.8	17.9	18.3	Avg.17.47

Pipe is flowing full

Length of level horizontal discharge pipe tested: _____

H in ft = 17.47 in/12 in/ft = 1.46 ft

Velocity (V) in Pipe (ft/s):

$V = (2 \times g \times H)^{0.5}$; where g is the acceleration due to gravity (32.2 ft/s^2)
$V = (2 \times 32.2 \times 1.46)^{0.5}$
V = 9.69 ft/s

Cross-Sectional Area (A) of Pipe (ft^2):

$A = \pi \times D^2/4$
$A = 3.14 \times 4^2/4$
A = 12.56 ft^2

Flow (Q) in Pipe (ft^3/s):

$Q = A \times V$
$Q = 12.56 \text{ ft}^2 \times 9.69 \text{ ft/s}$
Q = 121.7 ft^3/s

Conversion to gpm:

Q = 121.7 ft3/s x 448.8 gpm/cfs
Q = 54,618.9 gpm

Case 2. Partial Pipe Flow

Important Note: Refer to Appendix C in this Section or a geometry handbook, for assistance in determining the water flow area in pipes that are not flowing full or half full.

48" diameter pipe = 4 ft
Pipe flowing half full (depth of water in pipe 2 ft)
Length of level horizontal discharge pipe tested: _____

Manometer Readings H (inches)	16.9	17.3	17.0	16.7	17.5	17.7	17.6	17.8	17.9	18.3	**Avg.17.47**

H in ft = 17.47 in/12 in/ft = 1.46 ft

Velocity (V) in Pipe (ft/s):

$V = (2 \times g \times H)^{0.5}$; where g is the acceleration due to gravity (32.2 ft/s^2)
$V = (2 \times 32.2 \times 1.46)^{0.5}$
V = 9.69 ft/s

Cross-Sectional Area (A) of Pipe (ft^2):

$A_{part} = A/2$
$A = \pi \times D^2/4$
$A = 3.14 \times 4^2/4$
A = 12.56 ft^2
Apart = 12.56 ft^2/2
Apart = 6.28 ft^2

Flow (Q) in Pipe (ft^3/s):

$Q = A_{part} \times V$
Q = 6.28 ft^2 x 9.69 ft/s
Q = 60.85 ft^3/s

Conversion to gpm:

Q = 60.85 ft3/s x 448.8 gpm/cfs
Q = 27,309.4 gpm

Recommended References:

Chapter 13 in www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm.

www.1728.com/circsect.htm. Calculator for area of circle segment.

PROPELLER METER METHOD

The Following Conditions are Required:

- The measured pipe must be flowing full of water.
- The meter must be new or calibrated for the specific inside diameter (ID) of the pipe to be tested.
- The meter can be installed in a straight section of the pipe.
- Manufacturer's specifications for distance from pumps or pipe bends must be followed.
- This meter may also be used to calibrate a fixed propeller meter that is permanently installed on the pipe (such as a totalizing flow meter).

Test Procedure:
- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- The system should be operated until flow in the pipe is stabilized before beginning the test.
- Place and secure the propeller meter at the center of the pipe's circular cross-sectional area
- Record the totalizer reading on the meter at the start of the test.
- Run water through the pipe for 10 minutes, and record the ending totalizer reading.
- Subtract the beginning reading from the ending reading to obtain total gallons for the test.
- Divide the total gallons by 10 to obtain the average flow rate in gallons per minute.
- If the meter does not have a totalizer, record several flow rate (gpm) readings over a 10-minute period after flow stabilizes and simply average the values.

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____

(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Example Flow Verification Information, Data and Calculations:

Pipe inside diameter (D) = 6 inches

Length of level horizontal discharge pipe tested: _____

Test duration (T) = 10 minutes

Totalizer reading beginning = 12,070 gallons

Totalizer reading end = 18,185 gallons

Total flow volume (Vol) for 10-minute event (gal):

Vol = Totalizer reading ending - Totalizer reading beginning
Vol = 18,185 gal – 12,070 gal
Vol = 6,115 gal

Flow (Q) in pipe, gpm:

Q = Vol/T
Q = 6,115 gal/10 min
Q = 611.5 gpm

Recommended References:

Chapter 14 in www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm.

TRAJECTORY METHOD

Required Conditions:

- The pipe must be level (horizontal).
- The end of the discharge pipe must be flowing full.
- The straight length of pipe should be 8 to 10 times the diameter in length.
- The end of the pipe must be cut squarely.
- Measurement points must be easily accessed.

Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Allow flow in the pipe to occur for at least 15 minutes, to obtain stable and consistent conditions.
- The flow rate is derived from a horizontal pipe using the horizontal (X) and vertical (Y) distances to the top of the discharge stream. Refer to the figure in the example below.
- This method typically uses a "Y" distance of 4 or 12 Inches. However, in some cases the "X" direction governs the measurements where "X" is the distance from the end of the pipe to where the water stream impacts the surface of the receiving water body or ground surface.
- Typically, a straight edge and square are use to make the measurement.
- Repeat the measurements at least 3 times. Use the average of the measurements.
- Flow is then calculated using the equation shown in the example below.
- This is also referred to as the Purdue method.

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____ __

(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Example Flow Verification Information, Data and Calculations:
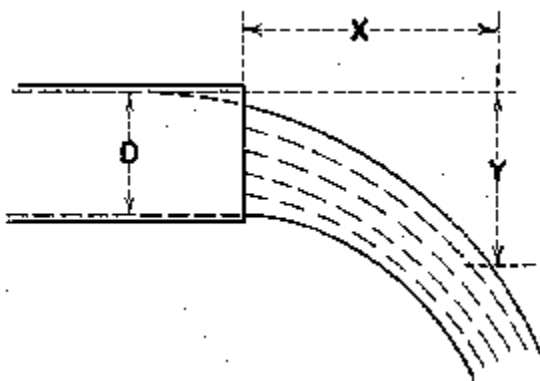
Pipe inside diameter (D) = 4 inches

Length of level horizontal discharge pipe tested: _____

Pipe is flowing full

Discharge Stream Measurements:

Horizontal (X) in inches	8	7	6	Avg. 7.0 in
Vertical (Y) in inches	4.0	4.0	4.0	Avg. 4.0 in

X in ft = 7.0 in/12 in/ft
X, ft = 0.58 ft

Y in ft = 4.0 in/12 in/ft
Y, ft = 0.33 ft

Velocity (V) in Pipe (ft/s):

$$V = X \times \frac{\sqrt{g}}{\sqrt{2Y}} = \sqrt{g} \times \frac{X}{\sqrt{2Y}} \;;$$

where g is the acceleration due to gravity (32.2 ft/s^2) and X, Y are expressed in ft.

$$V = \sqrt{32.2} \times \frac{X}{\sqrt{2Y}} = 5.67 \quad \times \frac{X}{\sqrt{2Y}}$$

$$V = 5.67 \times \frac{0.58}{\sqrt{2 \times 0.33}} = 4.05 \text{ ft/s}$$

Cross-Sectional Area (A) of Pipe (in^2):

A = π x D^2/4
A = 3.14 x 4^2/ 4
A = 12.56 in^2 = 12.56/144 ft^2 = 0.0872 ft^2

Flow (Q) in Pipe (ft^3/s):

Q = A x V;   where A is expressed in ft^2 and V is expressed in ft/s
Q = 0.0872 x 4.05 = 0.3532 ft^3/s

Conversion to Gallons per Minute (gpm):

Q = 0.3532 ft^3/s x 448.8 gpm/cfs = 158.6 gpm

Important Note: Flow (Q) can also be read directly from charts or tables given pipe diameter and X and Y readings.

Simplification: If X reading is taken in inches where Y = 12 inches, the equation for Q simplifies to: Q, gpm = 0.818 x D^2 x X; where D and X are in inches.

Recommended References:
Agricultural Coalition of South Florida. 2005. Methods for Calibrating, Measuring and Reporting Agricultural Water Use in South Florida, Draft. Clewiston, Florida.

Colt Industries, Inc. 1979. Hydraulic Handbook, 11th Edition. Fairbanks Morse Pump Division of Colt Industries. Kansas City, Kansas.

Karassik, I.J., W.C. Krutzsch, W.H. Fraser and J.P. Messina, eds. 1976. Pump Handbook. McGraw-Hill, Inc., New York.

Chapter 14 in www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm.

ULTRASONIC AND OTHER EXTERNAL FLOW METERS METHOD

For these instruments to function properly, pipe vibrations will need to be at a minimum. If vibrations cause undue fluctuations in readings and malfunctioning of the meter, select another method.

Required Conditions:

- Acceptable length of straight pipe away from pump or bends per manufacturer's specifications (generally 6 to 10 pipe diameters).
- Pipe is exposed and accessible.
- Pipe must flow full at point of measurement (the pipes of a pressurized irrigation system have full flow conditions).

Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Take at least 5 discrete velocity readings.
- Average the 5 velocity measurements.
- If your readings are in feet per second, multiply them by the circular area of the pipe in which you took the readings to calculate flow in cubic feet per second.
- Convert flow to gallons per minute.

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Example Flow Verification Information, Data and Calculations:

Instrument Readings:

TIME	VELOCITY READING (ft/s)
1:00 pm	8.56
1:01 pm	8.55
1:02 pm	8.57
1:03 pm	8.57
1:04 pm	8.55

Average Velocity (V) = 8.56 ft/s

Pipe inside diameter (D): 24 inches (2 ft)

Cross-Sectional Area of Pipe, A (ft^2):

A = (π x D^2)/4 (full pipe)
A = (π x 2^2)/4
A = 3.14 ft^2

Average Flow in Pipe (ft^3/s):

Q = Average Velocity x Cross-Sectional Area of Pipe
Q = 8.56 ft/s × 3.14 ft^2
Q = 26.88 ft^3/s

Conversion to Gallons per Minute (gpm):

Q = 26.88 ft^3/s x 448.8 gpm/cfs
Q = 12,063 gpm

Recommended References:

Chapters 11 and 14 in www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm.

VERTICAL PIPE METHOD

Required Conditions:

- The pipe must discharge to open air
- The pipe must be vertical and not inclined.
- You must have access by foot to the pipe.

Test Procedures:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Use a carpenter's square or a 90 degree folding scale to measure the vertical rise of the water spout (H) in inches above the edge of the pipe.
- Use a table (see below) or standard equation to determine the flow from your pipe, using H from above and the inside diameter of the pipe in inches.
- Repeat the above two steps at least two more times and report the average result of those H determinations.

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Example Flow Verification Information, Data and Calculations:

- Pipe inside diameter (D): 4 inches
- A level was used to check that the pipe was vertical (side to side and front to back).
- Rise of Water Spout above edge of Pipe:

Measurement Information: Measurement Number	Rise of Water Spout above Edge of Pipe "H" (inches)
1	6
2	5
3	7
AVERAGE	6

Average Flow from Pipe Using Table Below (Gallons per Minute):

- 205 gpm

Flow from Vertical Pipes (gpm)

Pipe Inside Diameter (inches)	Rise of Water Spout Above Edge of Pipe (inches)										
	3	3.5	4	4.5	5	5.5	6	7	8	10	12
2	38	41	44	47	50	53	56	61	65	74	82
3	81	89	96	103	109	114	120	132	141	160	177
4	137	151	163	174	185	195	205	222	240	269	299
6	318	349	378	405	430	455	480	520	560	635	700
8	567	623	684	730	776	821	868	945	1020	1150	1270
10	950	1055	1115	1200	1280	1350	1415	1530	1640	1840	2010

Reference: Colt Industries, 1974

The flow (Q in gpm) through the pipe is calculated according to the formula:

$$Q = 5.68 \times K \times D^2 \times H^{0.5}$$

where:
K is a coefficient which ranges from 0.87 to 0.97 for pipes with inside diameter between 2 and 6 inches
D = Pipe inside diameter (in)
H = Rise of water spout above edge of pipe (in)

Calculate Coefficient, K:

K = 0.87 for 2 inch diameter pipes and 0.97 for 6 inch diameter pipes, as long as H is within 6 inches to 24 inches. Linear interpolation can be used to adjust K for pipe diameters between 2 and 6 inches.

$K_{4 \text{ in pipe}}$ = 0.97 - [(4 − 2)/(6 − 2)] x (0.97 − 0.87)
$K_{4 \text{ in pipe}}$ = 0.92

Flow (Q) in Pipe (gpm):

$Q = 5.68 \times 0.92 \times 4^2 \times 6^{0.5}$
Q = 205 gpm

Important Note: Other pipe configuration flow tables can be found in Chapter 14 of the United States Bureau of Reclamation Water Measurement Manual on line at:
www.usbr.gov/pmts/hydraulics_lab/pubs/index.htm.

Recommended References:

Colt Industries, Inc. 1979. Hydraulic Handbook, 11th Edition. Fairbanks Morse Pump Division of Colt Industries. Kansas City, Kansas.

Karassik, I.J., W.C. Krutzsch, W.H. Fraser and J.P. Messina, eds. 1976. Pump Handbook. McGraw-Hill, Inc., New York.

Chapter 14 in www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm.

VOLUMETRIC FLOW METHOD

Required Conditions:

- The flow of water in the pipe is low enough that it can fill in a container over a period of no less than 15 seconds; or
- A large enough container is available such that it will take no less than 15 seconds to completely fill it with water from the small pipe being measured.
- A container is available such that you know its weight when empty and when full of water, or you know the total volume of water it can hold when full.
- The small pipe is positioned in such a way that you can temporarily direct its flow to the container chosen for the measurement without the use of flow altering connectors and pipes/hoses.
- A container is available such that you can transport it to the location where the small pipe is.

Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Place the empty container you chose at the discharge end of the small pipe so that it captures all the flow.
- Use a stop watch or a watch that is capable of reading in seconds, to determine the time it takes to completely fill the container.
- Repeat the above two steps at least two more times.

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____

(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Example Flow Verification Information, Data and Calculations:

- Pipe inside diameter: 4 inches

  - Flow from the pipe was directed to the container via a temporary PVC pipe extension that allowed free flow of water to the container with no addition of hydraulic head to the system.

- Container Information (choose only one below):

  a) Weight Information:
     - ✓ Weight of Container when Empty: 50 lbs
     - ✓ Weight of Container when Full of Water: 1719 lbs

  b) Volume Information:
     - ✓ Volume of Container: 200 gallons

Measurement Information:

Measurement Number	Time to Fill Container, T (Seconds)
1	18
2	20
3	22
AVERAGE TIME, T	20

Case 1. Weight Information

Convert Weight of Water to Volume (gal):

Weight of Water Only in Container: 1719 lbs – 50 lbs = 1669 lbs
Volume of Water in Container (Vol_{water}): 1669 lbs/62.4 lbs per ft^3 = 26.75 ft^3

Flow (Q) from Pipe (ft^3/s):

$Q = Vol_{water}$, ft^3/T, sec
$Q = 26.75$ ft^3/20 s
$Q = 1.34$ ft^3/s

Conversion to gpm:

$Q = 1.34$ ft^3/s x 448.8 gpm/cfs
$Q = 600$ gpm

Case 2. Volume Information

Flow (Q) from Pipe (gpm):

T, time to fill container full = 20 seconds
Container size = 200 gallons

$Q = Vol_{container}$, gal/(T, sec x Conversion Factor, seconds to minutes)
$Q = 200$ gal/(20 s x 1/60 min/s)
$Q = 600$ gpm

Important Note:. It is important that flow characteristics at the outlet where water is collected are not changed. Additionally, when using the weight method, it is recommended that the weight of a gallon of water that has passed through the system be measured.

Recommended References:

Jensen, M.E., ed. 1983. Design and Operation of Farm Irrigation Systems, Chapter 17. American Society of Agricultural Engineers. St. Joseph. Michigan.

Smajstrla, A. G., Harrison, D. S., and Zazueta, F. S. 1985. Agricultural Water Measurement. IFAS Bulletin 207. University of Florida Cooperative Extension Service. Gainesville, Florida.

WEIR METHOD

Required Conditions:

- A typical weir is a flash board riser with boards installed.
- The weir needs to be rectangular in shape and have water moving freely over its top
- The weir needs to be leveled
- The velocity of the water approaching the weir is low.
- The water approaching the weir needs to be free of trash.
- The level of the water approaching the weir needs to be high enough above the top of the weir, to be able to measure that water level.
- The water level downstream of the weir needs to be below the top of the weir.
- For other type of weirs or flow conditions (submerged, v-notch, and others), you will be required to retain a P.E. so that he/she can submit a calibration plan to SFWMD for review and approval.

Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Measure the height of the upstream water level above the top of the weir, or Head (H). This measurement needs to be taken a distance of at least one weir width, from the weir.
- Measure the width of the weir.
- All measurements should be as accurate as possible, and at worst, to the nearest 1/2 inch.
- Additional Comments:
  - The weir coefficient should be verified if the riser or canal width is less than 3 times the weir width.

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____ __
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Example Flow Verification Information, Data and Calculations:

Weir dimensions: Length of Crest, L = 2.50 ft
                      Top of Weir Elevation* = 9.65 ft

Water Surface Elevation (Upstream)*:   10.95 ft

Head on Weir (H):

H = Water Surface Elevation, ft* – Top of Weir Elevation, ft*
H = 10.95 – 9.65
H = 1.30 ft

* Important Note: Not necessary, if the height of water above the top of the weir can be measured directly.

Weir Equation:

Q, ft^3/s = C x L, ft x (H, ft)$^{1.5}$

    C = Weir Coefficient = 3.13

Flow (Q) in ft^3/s:

Q = 3.13 x 2.50 x 1.30$^{1.5}$
Q = 11.60 ft^3/s

Conversion to gpm:

$Q = 11.60$ ft^3/s x 448.8 gpm/cfs
$Q = 5205$ gpm

Recommended References:

Colt Industries, Inc. 1979. <u>Hydraulic Handbook</u>, 11th Edition. Fairbanks Morse Pump Division of Colt Industries. Kansas City, Kansas.

ISCO, Inc. 1992. <u>Open Channel Flow Measurement Handbook</u>, 3rd Edition. ISCO, Inc. Lincoln Nebraska.

Chapter 7 in www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm.

APPENDIX A

FLOW VERIFICATION (CALIBRATION)

METHOD SELECTION PROCESS

CALIBRATION LOCATION: PIPES

IF YOUR PIPE IS FLOWING FULL:

> Propeller Meter
> Ultrasonic Totalizing Meter (External)
> Electromagnetic Insertion Meter
> Flow Probe Meter
> Doppler Meter (External)
> Orifice Manometer Method
> Pitot Tube Manometer Method
> Trajectory Method
> Volumetric Flow Method
> Vertical Pipe Method
> Dye Tracer or Color Method
> Dye Fluorometry or Chemical Gauging Method

IF YOUR PIPE IS FLOWING PARTIALLY FULL:

> Electromagnetic Insertion Meter
> Flow Probe Meter
> Pitot Tube Manometer Method
> California Method
> Volumetric Flow Method
> Dye Tracer or Color Method
> Dye Fluorometry or Chemical Gauging Method

CALIBRATION LOCATION: OPEN DITCHES OR CHANNELS

> Electromagnetic Meter
> Flow Probe Meter
> Dye Tracer or Color Method
> Dye Fluorometry or Chemical Gauging Method
> Weir
> Float Velocity Method

APPENDIX B

FLOW VERIFICATION (CALIBRATION) FORMS

(IN ALPHABETICAL ORDER)

FLOW VERIFICATION (CALIBRATION) FORM

CALIFORNIA METHOD
(See: Methods, Section C in Handbook)

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Flow Verification Information, Data and Calculations:

Pipe inside diameter (D): _____(inches)

(D) Inches ÷ 12 = (D) _____ (feet)

Length of level horizontal discharge pipe tested: _____(feet)

If the flow is always constant because it is not controlled via a control valve, variable RPM/speed pump, or other method, do the following:

Gap readings (**a**):
    Minute 1_____(inch)
    Minute 3_____(inch)
    Minute 5_____(inch)

Average gap reading (**a**) = _____ Inches

(**a**) Inches ÷ 12 = (**a**)_____(ft)

Equation: (The calculation will require a scientific calculator)

Flow (**Q**) in pipe, cfs (cubic feet per second) when (a) and (D) are in (ft)

$$\mathbf{Q} = 8.69 \times (1 - a / D)^{1.88} \times D^{2.48}$$

$$\mathbf{Q} = 8.69 \times (\underline{\hspace{2cm}})^{1.88} \times \underline{\hspace{2cm}}^{2.48}$$

Q = _____(cfs)

Conversion Equation: cfs to gpm (gallons per minute)

Q = _____ (cfs) **X** 448.8 gpm/cfs

Q = _____ gpm

If the flow changes due to control valves, variable RPM/speed pumps or other methods, repeat the process above to record those variable flows. These flows can be the maximum, minimum, and median flows expected to be used during typical water use conditions.

Flow condition 1 Max. Pump RPM = _____   **Q** = _____gpm

Flow condition 2 Med. Pump RPM= _____   **Q** = _____gpm

Flow condition 3 Min. Pump RPM= _____   **Q** = _____gpm

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

Doppler Meter Method

For Facilities Using Totalizing Flow Meters <u>Only</u>
(See: Methods, Section C in Handbook)

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc) _____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: <u>Totalizing Flow Meter</u>

_____

Flow Verification Information, Data and Calculations:

Permanent Existing Meter Information:
  Manufacturer make, model, and serial number: _____

Doppler Meter Used to Calibrate Permanent Existing Meter:
  Manufacturer make, model, and serial number: _____
  Last calibration date of the Ultrasonic Flow Meter _____

Test Site Information:
  Pipe material _____

  Pipe inside diameter _____

  Transducer spacing _____

Test location:

    (Distance from Permanent Existing Meter _____ (ft/in)

    (upstream / downstream) _____

Permanent Existing Meter reading (**P**):
    Start Volume: _____ gal
    End Volume: _____ gal
    Elapsed test time _____ min
    (**P**) Resulting Flow rate _____ gpm

Doppler Flow Meter reading (**E**):

    Start Volume: _____ gal
    End Volume: _____ gal
    Elapsed test time _____ min
    (**E**) Resulting Flow rate _____ gpm

Note: To reduce possible error, this comparative test will be performed simultaneously, whether the instrument used records in total volume (gal) per unit time or the standard (gpm) flow rate.

Equation for calculating correction factor of Permanent Existing Meter:

*1 ÷ **P/E** = Correction Factor*

where P = Permanent Existing Meter (gpm) and E = External Flow Meter (gpm)

Permanent Existing Meter Correction Factor (**PMCF**) = _____

If the flow changes due to control valves, variable RPM/speed pumps or other methods, repeat the process above to record those variable flows. These flows can be the maximum, minimum, and median flows expected to be used during typical water use conditions.

Flow condition 1 Max. Pump RPM or valve full open = _____   Q = _____gpm

Flow condition 2 Med. Pump RPM or valve half open = _____   Q = _____gpm

Flow condition 3 Min. Pump RPM or valve quarter open =_____   Q = _____gpm

PMCF (MAX) = _____

PMCF (MED) = _____

PMCF (MIN) = _____

If necessary, attach on separate page(s) all calculations, notes and photos to clearly identify the test site conditions and the obtained results shown above.

Note *(discovered problems)*

_____

*(Recommendations)*_____

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad=portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

Doppler Meter Method

For Non Metered Accounting Facilities
(See: Methods, Section C in Handbook)

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc) _____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____
_____

Flow Verification Information, Data and Calculations:

Doppler Flow Meter used: _____

(manufacturer's make, model number)

Last calibration date of the Doppler Flow Meter: _____

Test Site Information:

Pipe material tested_____

Pipe inside diameter _____inches

Pipe wall thickness _____inches

Transducer spacing _____inches

Test location: Distance from potential turbulent flow (ex. valve, elbow, etc.):
(upstream) _____ (ft/in)
(downstream) _____ (ft/in)

Doppler Flow Meter reading:

Start Volume: _____gal

End Volume: _____gal

Elapsed test time_____min

Resulting Flow rate = _____gpm

If the flow changes due to control valves, variable RPM/speed pumps or other methods, repeat the process above to record those variable flows. These flows can be the maximum, minimum, and median flows expected to be used during typical water use conditions.

Flow condition 1 Max. Pump RPM or valve full open = _____   Q = _____gpm
Flow condition 2 Med. Pump RPM or valve half open = _____   Q = _____gpm
Flow condition 3 Min. Pump RPM or valve quarter open =_____   Q = _____gpm

If necessary, attach on separate page(s) all calculations, notes and photos to clearly identify the test site conditions and the obtained results.

The flow rate of each zone will be required for multiple zone systems.
If necessary, attach on separate page(s) all calculations, notes and photos to clearly identify the test site conditions and the obtained results.

Note *(discovered problems)* _____

*(Recommendations)*_____

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

DYE TRACER OR COLOR METHOD
(See: Methods, Section C in Handbook)

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.) _____

Withdrawal type (pumped, gravity, flow well, other) _____

Facility water use accounting method _____

_____

Flow Verification Information, Data and Calculations:

Uniform Canal Section Used:
- (A) Bottom width: _____ft
- (B) Width at water surface: _____ft
- (C) Water depth: _____ft
- (D) Distance along canal between start and end points: _____ft

If the flow is always constant because it is not controlled via a control valve, variable RPM/speed pump, or other method, do the following:

Stopwatch Readings:

Reading	Travel Time (T) in Seconds
1	
2	
3	
AVERAGE TIME	(T) =

Average Water Velocity in Canal (V), in Feet per Second:
V = D/T
V = _____ft/sec

Canal Water Flow Area in Square Feet:
Area = (A + B) **X** C/2
Area = _____ft²

Average flow in Canal (Q), in Cubic Feet per Second (cfs):
Q = Area **X** (**V**)
Q = _____cfs

Conversion from cfs to gpm
Q = cfs **X** 448.8 gpm/cfs
Q = _____ gpm

If the flow changes due to control valves, variable RPM/speed pumps or other methods, repeat the process above to record those variable flows. These flows can be the maximum, minimum, and median flows expected to be used during typical water use conditions.

Flow condition 1 Max. Pump RPM = _____   **Q** = _____gpm
Flow condition 2. Med. Pump RPM= _____   **Q** = _____gpm
Flow condition 3. Min. Pump RPM= _____   **Q** = _____gpm

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

ELECTROMAGNETIC, FLOW PROBE AND OTHER VELOCITY FLOW METER METHODS
(See: Methods, Section C in Handbook)

Full Pipe (Case 1)

General Permit Information Required:

Permit Number/App Number   _____/_____

Project Name _____

Site Contact/Phone Number   _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.) _____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Flow Verification Information, Data and Calculations:

Flow Verification Meter used (manufacturer's make and model number)

_____

Last calibration date of the Verification Meter_____

If the flow is always constant because it is not controlled via a control valve, variable RPM/speed pump, or other method, do the following:

Velocity meter readings: velocity (V) feet / second (ft/s)

   1) _____ 2)_____ 3)_____ 4)_____ 5) _____
   6) _____ 7) _____ 8) _____ 9) _____ 10) _____

Average Velocity (V) = _____ft/s

Area (**A**)= π **X** r²
π = 3.14
r = inside pipe diameter (ft) **/** 2
Area (**A**) = _____ ft²

Average flow in Pipe (Q), in Cubic Feet per Second (cfs):

Q = Area (**A**) **X** Average Velocity (**V**)
Q = _____cfs

Conversion from cfs to gpm

Q =cfs **X** 448.8 gpm/cfs
Q = _____ gpm

If the flow changes due to control valves, variable RPM/speed pumps or other methods, repeat the process above to record those variable flows. These flows can be the maximum, minimum, and median flows expected to be used during typical water use conditions.

Flow condition 1 Max. Pump RPM or valve full open = _____   **Q** = _____gpm
Flow condition 2 Med. Pump RPM or valve half open = _____   **Q** = _____gpm
Flow condition 3 Min. Pump RPM or valve quarter open =_____ **Q** =_____gpm

NOTE:
The flow rate of each zone will be required for multiple zone systems.
If necessary, attach on separate page(s) all calculations, notes and photos to clearly identify the test site conditions and the obtained results.

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

ELECTROMAGNETIC, FLOW PROBE AND OTHER VELOCITY FLOW METER METHODS
(See: Methods, Section C in Handbook)

Partially Full Pipe (Case 2)

General Permit Information Required:

Permit Number/App Number_____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.) _____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Flow Verification Information, Data and Calculations:

Flow Verification Meter used (manufacturer's make and model number)

_____

Last calibration date of the Verification Meter _____

Velocity meter readings: velocity (**V**) feet / second (ft/s)

   2) _____   2)_____   3)_____   4)_____   5) _____

   6) _____   7)_____   8)_____   9)_____   10)_____

Average (**V**) = _____ft/s

Cross-sectional Area of Partially filled Pipe (ft²):

- **Inside diameter (D) = _____(ft)**
- **Wet depth (d) = _____(ft)**
- **d/D =_____**
- **Multiplication Factor (from table below) =_____**

$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$	$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$	$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$	$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$
0.01	0.0013	0.26	0.1623	0.51	0.4027	0.76	0.6405
0.02	0.0037	0.27	0.1711	0.52	0.4127	0.77	0.6489
0.03	0.0069	0.28	0.1800	0.53	0.4227	0.78	0.6573
0.04	0.0105	0.29	0.1890	0.54	0.4327	0.79	0.6655
0.05	0.0147	0.3	0.1982	0.55	0.4426	0.8	0.6736
0.06	0.0192	0.31	0.2074	0.56	0.4526	0.81	0.6815
0.07	0.0242	0.32	0.2167	0.57	0.4625	0.82	0.6893
0.08	0.0294	0.33	0.2260	0.58	0.4724	0.83	0.6969
0.09	0.0350	0.34	0.2355	0.59	0.4822	0.84	0.7043
0.1	0.0409	0.35	0.2450	0.6	0.4920	0.85	0.7115
0.11	0.0470	0.36	0.2546	0.61	0.5018	0.86	0.7186
0.12	0.0534	0.37	0.2642	0.62	0.5115	0.87	0.7254
0.13	0.0600	**0.38**	**0.2739**	0.63	0.5212	0.88	0.7320
0.14	0.0668	0.39	0.2836	0.64	0.5308	0.89	0.7384
0.15	0.0739	0.4	0.2934	0.65	0.5404	0.9	0.7445
0.16	0.0811	0.41	0.3032	0.66	0.5499	0.91	0.7504
0.17	0.0885	0.42	0.3130	0.67	0.5594	0.92	0.7560
0.18	0.0961	0.43	0.3229	0.68	0.5687	0.93	0.7612
0.19	0.1039	0.44	0.3328	0.69	0.5780	0.94	0.7662
0.2	0.1118	0.45	0.3428	0.7	0.5872	0.95	0.7707
0.21	0.1199	0.46	0.3527	0.71	0.5964	0.96	0.7749
0.22	0.1281	0.47	0.3627	0.72	0.6054	0.97	0.7785
0.23	0.1365	0.48	0.3727	0.73	0.6143	0.98	0.7816
0.24	0.1449	0.49	0.3827	0.74	0.6231	0.99	0.7841
0.25	0.1535	0.5	0.3927	0.75	0.6319	1	0.7850

D² X Multiplication Factor = Wet cross-sectional area (A) = _____ ft²

Average flow in partially filled Pipe (**Q**), in Cubic Feet per Second (cfs):

Q = (**A**) Wet cross-sectional area **X** Average Velocity (**V**)

Q = _____cfs

<u>Conversion from cfs to gpm</u>

Q =cfs **X** 448.8 gpm/cfs

Q = _____ gpm

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

ELECTROMAGNETIC, FLOW PROBE AND OTHER VELOCITY FLOW METER METHODS
(See: Methods, Section C in Handbook)

Open Trapezoid Channel (Case 3)

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.) _____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facilities water use accounting method: _____

Flow Verification Information, Data and Calculations:

Flow Verification Meter used: (manufacturer's make and model number)

_____

Last calibration date of the Verification Meter: _____

(CONTINUES ON NEXT PAGE)
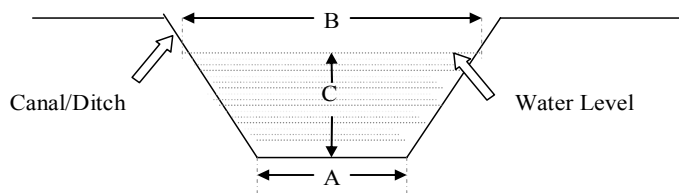
Canal Section used:
- (**A**) Bottom Width: _____ft
- (**B**) Width at water surface: _____ft
- (**C**) Water Depth: _____ft

Electromagnetic, Flow Probe or other Test-Meter Readings:

Velocity
Readings   ___ ___ ___ ___ ___ ___ ___ ___ ___ ___   **Avg.
(ft/s)   Velocity:__**

Average Flow in the Canal Gallons per Minute (gpm):

= Canal Water Flow Area x Average Water Velocity in the Canal

Canal Water Flow Area (Square Feet):

Water Flow Area = (A + B) **x** C / 2
Water Flow Area = (_____ft **+** _____ft) **x** _____ft / 2
Water Flow Area = _____ ft^2

Average Flow in the Canal (gpm):
Q = Water Flow Area **x** Average Flow Velocity
Q = _____ ft^2 **x** _____ ft/s **x** 448.9 conversion to gpm
Q = _____ gpm

Open Canal Flow for <u>OTHER</u> Shaped Ditch Sections:

<u>Important Note:</u> For assistance in selecting the best method for measuring flow, determining the water flow area of non-uniform canal sections and the technique for collecting velocity data at multiple points, please refer to Section B and Section C (Appendix A and C) in this document. The data collection form (FD 9000-11) for Streamgaging method may be used for all non- trapezoidal shaped open channels.

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site: http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

FLOAT VELOCITY METHOD
(See: Methods, Section C in Handbook)

General Permit Information Required:

Permit Number/App Number   _____/_____

Project Name _____

Site Contact/Phone Number   _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.) _____

Withdrawal type (pumped, gravity, flow well, other) _____

Facility water use accounting method: **_____**
_____

Flow Verification Information, Data and Calculations:

- **This method should be selected as a last resort for flow verification. If possible, other methods listed in Section C should be used.**

- **Ditch Section Used (trapezoidal shaped cross-section):**
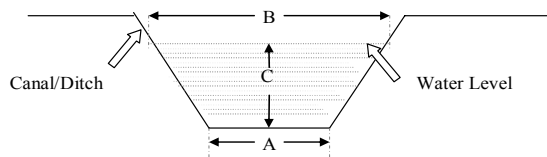
- ○ **(A) Bottom width: ___ ft**
- ○ **(B) Width at water surface: ___ ft**
- ○ **(C) Water depth: ___ ft**
- ○ **(D) Distance along ditch between starting and ending points: ____ ft**

- **Description of Floats used for test:** _____

- **Number of Floats used (from table below):** _____

Ditch Width at Water Surface (ft)	Number of Floats
0 - 10	1
10 - 15	2
15 - 20	3
20 - 25	4

Note: For ditches wider than 15 ft. use the numbers of floats indicated in the table above. Add the corresponding numbers of floats and rows for Run 1 through Run 3. Attach all additional float readings on a separate page.

- **Float Readings:**

Run 1

Float Number	Travel Time (T, Seconds)
1	
2	
AVERAGE (T¹) =	

Run 2

Float Number	Travel Time (T, Seconds)
1	
2	
AVERAGE (T²) =	

Run 3

Float Number	Travel Time (T, Seconds)
1	
2	
AVERAGE (T³) =	

Average Travel Time for All Floats and All Runs:

T = (T¹ + T² + T³) / 3 = _____ seconds

Average Water Velocity in the Ditch (Feet per Second):

V = 0.85 x D ft/T seconds
    Where: 0.85 is a constant that adjusts surface velocity to average channel velocity, D is the test travel distance and T is the average time to travel the test distance.

V = 0.85 x ___ ft/____ seconds

V = _____ ft/s

Cross-Sectional Area of Channel Section Used for Test:

A = (a + b) x c/2

A = (_____ ft + _____ ft) x _____ ft/2

$$A = \_\_\_\_\_ \text{ ft}^2$$

Average Flow in the Ditch (ft³/s):

Q = V x A

$$Q = \_\_\_\_ \text{ ft/s} \times \_\_\_\_ \text{ ft}^2$$

$$Q = \_\_\_\_ \text{ ft}^3/\text{s}$$

Conversion to Gallons per Minute (gpm):

Q in ft³/s X 448.8 = Q in gpm

Q = _____ gpm

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____

Company and Title: _____

Phone number: _____

Test Date _____

ORIFICE MANOMETER METHOD
OPEN PIPE DISCHARGE
(See: Methods, Section C in Handbook)

General Permit Information Required:

Permit Number/App Number   _____/_____

Project Name _____

Site Contact/Phone Number   _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.) _____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method _____

Flow Verification Information, Data and Calculations:

Orifice Manometer used: _____
 (manufacturer's make and model number)

Last calibration date of the Orifice Manometer: _____

NOTE: Pipe must be flowing full when orifice plate is installed

Pipe Inside Diameter (D) = ____ inches

Orifice Diameter (d) = ____ inches

Length of Level Horizontal Discharge Pipe Tested: _____ft

Manometer Measurements:

Levels of Water (H) in Manometer:
   (H¹) _____ inch,   **(H²)** _____ inch,   **(H³)** _____ inch

Average hydraulic head (H):

   H = (H¹ + H² + H³) / 3 = _____ inches

Coefficient (C) from graph below:

Ratio of orifice diameter to pipe diameter = (d) **inches /** (D) **inches;**
Orifice diameter (d) = _____ inches
Pipe inside diameter (D) = _____ inches
Ratio = _____
From graph below, (C) = _____

Graph: VALUE OF C IN ORIFICE FORMULA vs RATIO OF ORIFICE DIAMETER TO PIPE DIAMETER

$Q = CA\sqrt{2gh} = 8.02\, CA\sqrt{h}$
Q IS GAL. PER MIN.
C IS FROM CURVE
A IS ORIFICE AREA, SQ. INCHES
h IS HEAD, INCHES
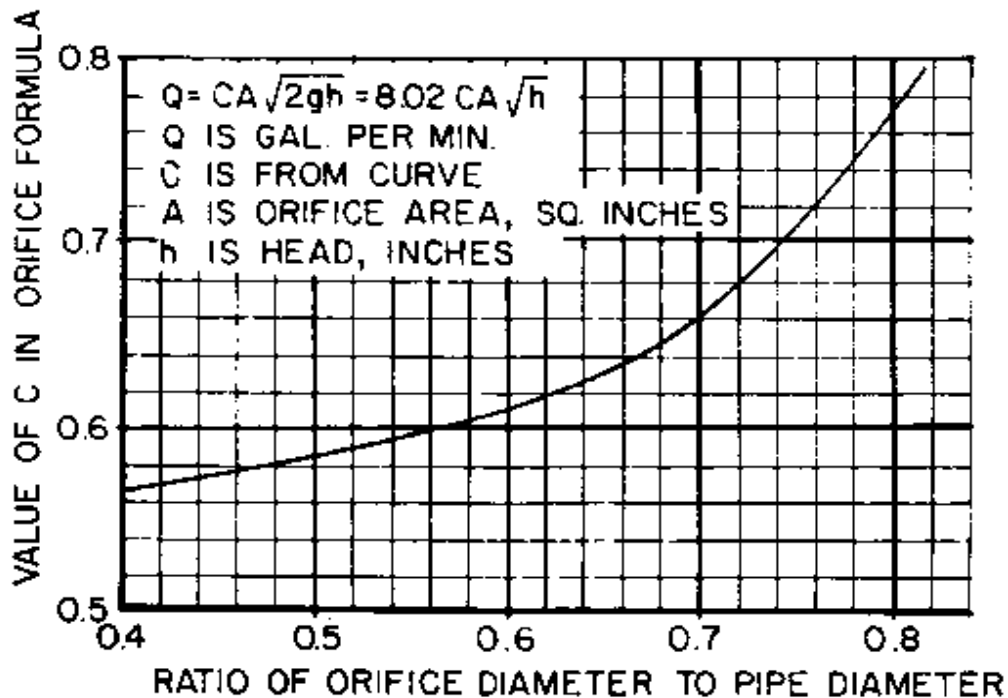
Cross-Sectional Area (A) of Orifice (in²):

$A = (\pi \times d^2)/4$
$A = (3.14 \times \underline{\quad}^2)/4$
$A = \underline{\qquad} \ in^2$

Flow (Q) in Pipe (gpm):

$$Q = 8.02 \times C \times A \times H^{0.5}$$

Q = 8.02 x _____ x _____ x ____

Q = _____ gpm

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____

Company and Title: _____

Phone number: _____

Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

PITOT TUBE MANOMETER METHOD
(See: Methods, Section C in Handbook)

FULL PIPE FLOW (Case 1)

General Permit Information Required:

Permit Number/App Number_____/_____

Project Name_____

Site Contact/Phone Number _____/_____

District Facility ID _____

__

*(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)*

Withdrawal source: (ex. well, lake, canal name, etc.) _____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Flow Verification Information, Data and Calculations:

Pitot Tube instrument used: _____
(manufacturer's make and model number)

Last calibration date of the Pitot Tube: _____

Pipe Inside Diameter = _____ inches / 12 inches per foot = _____ ft

Length of leveled horizontal discharge pipe tested: _____ ft

Manometer Readings, H (inches)	____	____	____	____	____	____	____	____	____	____	Average (H)_____

(H) in ft = _____ inches / 12 inches / ft = _____ft

Velocity (V) in Pipe (ft/s):

V = $\sqrt{2 \times g \times H}$; where g is the acceleration due to gravity (32.2 ft/s^2)

V = $\sqrt{2 \times 32.2 \times \underline{\quad} ft}$

V = _____ ft/s

Cross-Sectional Area (A) of Pipe (ft^2):

A = π x D^2/4
A = 3.14 x _____^{2}/ 4
A = _____ ft^2

Flow (Q) in Pipe (ft^3/s):

Q = A x V
Q = _____ ft^2 x _____ ft/s
Q = _____ ft^3/s

Conversion to gpm:

Q = _____ ft^3/s x 448.8 gpm/cfs
Q = _____ gpm

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal

form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

PITOT TUBE MANOMETER METHOD
(See: Methods, Section C in Handbook)

PARTIAL PIPE FLOW (Case 2)

General Permit Information Required:

Permit Number/App Number_____/_____

Project Name _____

Site Contact/Phone Number_____/_____

District Facility ID _____

(If not known, use site name and GPS coordinates or site map referencing

location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.) _____

Withdrawal type (pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

_____

Flow Verification Information, Data and Calculations:

Pitot Tube instrument used: _____
(manufacturer's make and model number)

Last calibration date of the Pitot Tube: _____

Manometer Readings, H (inches)	____	____	____	____	____	____	____	____	____	____	Average (H)=____

Length of Leveled Horizontal Discharge Pipe Tested: _____ ft

(H) = _____ inches / 12 inches / ft = _____ ft

<u>**Velocity (V) in Pipe (ft/s):**</u>

V = $\sqrt{2 \times g \times H}$ **; where g is the acceleration due to gravity (32.2 ft/s^2)**

V = $\sqrt{2 \times 32.2 \times \underline{\hspace{1cm}} ft}$

(V) = _____ ft/s

<u>**Cross-Sectional Area (A) of Partially filled Pipe (ft^2):**</u>

<u>**Important Note:**</u>
To determine the water flow area in pipes that are not flowing full or half full measure the inside pipe diameter D and height of the water in the pipe, d.

Inside D

d = Water depth
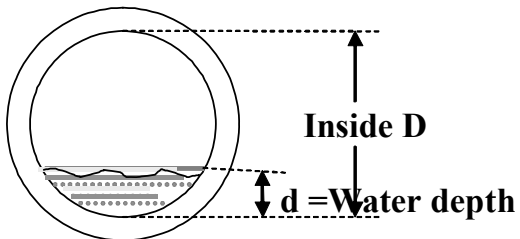
Pipe Inside Diameter (D) = _____ inches / 12 = _____ ft

Wet Depth in pipe (d): _____ inches / 12 = _____ ft

Based on the value $\dfrac{d}{D}$ **find the multiplication factor in the table below:**

(SEE TABLE ON NEXT PAGE)

$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$		$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$		$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$		$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$
0.01	0.0013		0.26	0.1623		0.51	0.4027		0.76	0.6405
0.02	0.0037		0.27	0.1711		0.52	0.4127		0.77	0.6489
0.03	0.0069		0.28	0.1800		0.53	0.4227		0.78	0.6573
0.04	0.0105		0.29	0.1890		0.54	0.4327		0.79	0.6655
0.05	0.0147		0.3	0.1982		0.55	0.4426		0.8	0.6736
0.06	0.0192		0.31	0.2074		0.56	0.4526		0.81	0.6815
0.07	0.0242		0.32	0.2167		0.57	0.4625		0.82	0.6893
0.08	0.0294		0.33	0.2260		0.58	0.4724		0.83	0.6969
0.09	0.0350		0.34	0.2355		0.59	0.4822		0.84	0.7043
0.1	0.0409		0.35	0.2450		0.6	0.4920		0.85	0.7115
0.11	0.0470		0.36	0.2546		0.61	0.5018		0.86	0.7186
0.12	0.0534		0.37	0.2642		0.62	0.5115		0.87	0.7254
0.13	0.0600		**0.38**	**0.2739**		0.63	0.5212		0.88	0.7320
0.14	0.0668		0.39	0.2836		0.64	0.5308		0.89	0.7384
0.15	0.0739		0.4	0.2934		0.65	0.5404		0.9	0.7445
0.16	0.0811		0.41	0.3032		0.66	0.5499		0.91	0.7504
0.17	0.0885		0.42	0.3130		0.67	0.5594		0.92	0.7560
0.18	0.0961		0.43	0.3229		0.68	0.5687		0.93	0.7612
0.19	0.1039		0.44	0.3328		0.69	0.5780		0.94	0.7662
0.2	0.1118		0.45	0.3428		0.7	0.5872		0.95	0.7707
0.21	0.1199		0.46	0.3527		0.71	0.5964		0.96	0.7749
0.22	0.1281		0.47	0.3627		0.72	0.6054		0.97	0.7785
0.23	0.1365		0.48	0.3727		0.73	0.6143		0.98	0.7816
0.24	0.1449		0.49	0.3827		0.74	0.6231		0.99	0.7841
0.25	0.1535		0.5	0.3927		0.75	0.6319		1	0.7850

Multiplication Factor = _____

Wet cross-sectional area (**A**) = **D^2** **X** Multiplication Factor
Wet cross-sectional area (**A**) = _____ft²

Average flow in partially filled Pipe (Q), in Cubic Feet per Second (cfs):

Q = (**A**) X (**V**)
Q = _____cfs

Conversion from cfs to gpm

Q = cfs X 448.8 gpm/cfs
Q = _____ gpm

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form

can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad=portal &_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

Propeller Meter Method

For Facilities Using Totalizing Flow Meters <u>Only</u>
(See: Methods, Section C in Handbook)

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc) _____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: <u>Totalizing Flow Meter</u>

_____

Flow Verification Information, Data and Calculations:

Permanent Existing Meter Information:
  Manufacturer make, model, and serial number: _____

Propeller Meter Used to Calibrate Permanent Existing Meter:
  Manufacturer make, model, and serial number: _____
  Last calibration date of the Propeller Flow Meter _____

Test Site Information:

Pipe material _____

Pipe inside diameter   _____

Transducer spacing _____

Test location:

   (Distance from Permanent Existing Meter _____ (ft/in)

   (upstream / downstream) _____

Permanent Existing Meter reading (**P**):
   Start Volume: _____ gal
   End Volume: _____ gal
   Elapsed test time _____ min
   (**P**) Resulting Flow rate _____ gpm

Propeller Flow Meter reading (**E**):

   Start Volume: _____ gal
   End Volume: _____ gal
   Elapsed test time _____ min
   (**E**) Resulting Flow rate _____ gpm

 Note: To reduce possible error, this comparative test will be performed simultaneously, whether the instrument used records in total volume (gal) per unit time or the standard (gpm) flow rate.

Equation for calculating correction factor of Permanent Existing Meter:

*1 ÷ **P/E** = Correction Factor*

where P=Permanent Existing Meter (gpm) and E= External Flow Meter (gpm)

Permanent Existing Meter Correction Factor (**PMCF**) = _____

If the flow changes due to control valves, variable RPM/speed pumps or other methods, repeat the process above to record those variable flows. These flows can be the maximum, minimum, and median flows expected to be used during typical water use conditions.

Flow condition 1 Max. Pump RPM or valve full open = _____   Q = _____gpm

Flow condition 2 Med. Pump RPM or valve half open = _____   Q = _____gpm

Flow condition 3 Min. Pump RPM or valve quarter open =_____   Q = _____gpm

PMCF (MAX) = _____

PMCF (MED) = _____

PMCF (MIN) = _____

If necessary, attach on separate page(s) all calculations, notes and photos to clearly identify the test site conditions and the obtained results shown above.

Note *(discovered problems)* _____

*(Recommendations)*_____

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

Propeller Meter Method

For Non Metered Accounting Facilities
(See: Methods, Section C in Handbook)

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc) _____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

 Facility water use accounting method: _____
_____

Flow Verification Information, Data and Calculations:

Propeller Flow Meter used: _____

(manufacturer's make, model number)

Last calibration date of the Propeller Flow Meter: _____

Test Site Information:

 Pipe material tested_____

 Pipe inside diameter _____ inches

 Pipe wall thickness _____ inches

 Transducer spacing _____ inches

 Test location: Distance from potential turbulent flow (ex. valve, elbow, etc.):
 (upstream) _____ (ft/in)
 (downstream) _____ (ft/in)

Propeller Flow Meter reading:

Start Volume: _____gal

End Volume: _____gal

Elapsed test time_____min

Resulting Flow rate = _____gpm

If the flow changes due to control valves, variable RPM/speed pumps or other methods, repeat the process above to record those variable flows. These flows can be the maximum, minimum, and median flows expected to be used during typical water use conditions.

Flow condition 1 Max. Pump RPM or valve full open = _____   Q = _____gpm
Flow condition 2 Med. Pump RPM or valve half open = _____   Q = _____gpm
Flow condition 3 Min. Pump RPM or valve quarter open =_____   Q = ____gpm

If necessary, attach on separate page(s) all calculations, notes and photos to clearly identify the test site conditions and the obtained results.

The flow rate of each zone will be required for multiple zone systems.
If necessary, attach on separate page(s) all calculations, notes and photos to clearly identify the test site conditions and the obtained results.

Note *(discovered problems)* _____

*(Recommendations)*_____

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

TRAJECTORY METHOD
(See: Methods, Section C in Handbook)

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____

(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)_____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

_____

Flow Verification Information, Data and Calculations:
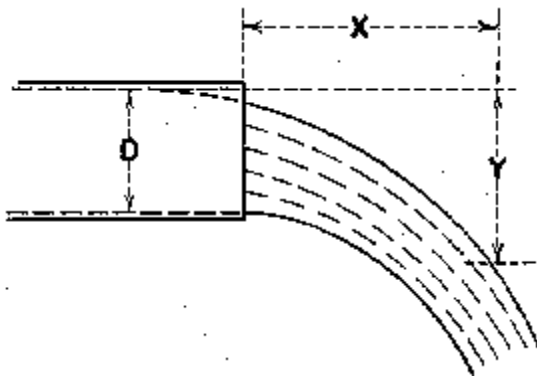
Pipe is flowing full

Information from the diagram shown above:

Pipe inside diameter (D): _____(inches)
(D) inches ÷ 12 = (D) _____feet (ft)

(R) Pipe radius = (D)ft ÷ 2 = _____(ft)

Length of level horizontal discharge pipe tested: _____(ft)

(X) pitch in inches _____ , _____, _____, _____
(X) average inches ÷ 12 = (X) _____ (ft)

(Y) fall in inches_____ , _____, _____, _____
(Y) average inches ÷ 12 = (Y) _____ (ft)

If the flow is always constant because it is not controlled via a control valve, variable RPM/speed pump, or other method, do the following:

Velocity (V) in Pipe (ft/s):

$$V = X \times \frac{\sqrt{g}}{\sqrt{2Y}} = \sqrt{g} \times \frac{X}{\sqrt{2Y}} \;;$$

where g is the acceleration due to gravity (32.2 ft/s^2) and X, Y are expressed in ft.

$$V = \sqrt{32.2} \times \frac{X}{\sqrt{2Y}} = 5.67 \times \frac{X}{\sqrt{2Y}}$$

$$V = 5.67 \times \frac{\overline{\qquad}}{\sqrt{2x}\underline{\qquad}} = \underline{\quad} \text{ft/s}$$

Cross-Sectional Area (A) of Pipe (ft^2):

A = π x (R)²
A = 3.14 x _____
A = _____ (ft^2)

Flow (Q) Equation:
Q= A x V; where A is expressed in ft^2 and V is expressed in ft/s
Q= _____ft^2 x _____ ft/s
Q = _____ (cfs)

Conversion Equation: (csf) to gpm (gallons per minute)
Q = _____(cfs) X **448.8 gpm / (cfs)**
Q = _____ **gpm**

If normal operations use a control valve or variable RPM pump to regulate flows repeat the above to simulate the operational conditions anticipated. These can be the maximum, minimum, and median flows expected.

Flow condition 1 Max. Pump RPM = _____   Q = _____gpm
Flow condition 2 Med. Pump RPM= _____   Q = _____gpm
Flow condition 3 Min. Pump RPM= _____   Q = _____gpm

If necessary, attach on separate page(s) all calculations, notes and photos to clearly identify the test site conditions and the obtained results shown above.

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

Ultrasonic Meter Method

For Facilities Using Totalizing Flow Meters <u>Only</u>
(See: Methods, Section C in Handbook)

<u>General Permit Information Required:</u>

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc) _____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: <u>Totalizing Flow Meter</u>

_____

<u>Flow Verification Information, Data and Calculations:</u>

Permanent Existing Meter Information:
 Manufacturer make, model, and serial number: _____

Ultrasonic Meter Used to Calibrate Permanent Existing Meter:
 Manufacturer make, model, and serial number: _____
 Last calibration date of the Ultrasonic Flow Meter _____

Test Site Information:

Pipe material _____

Pipe inside diameter _____

Transducer spacing _____

Test location:

      (Distance from Permanent Existing Meter _____ (ft/in)

      (upstream / downstream) _____

Permanent Existing Meter reading (**P**):
    Start Volume: _____ gal
    End Volume: _____ gal
    Elapsed test time _____ min
    (**P**) Resulting Flow rate _____ gpm

Ultrasonic Flow Meter reading (**E**):

    Start Volume: _____ gal
    End Volume: _____ gal
    Elapsed test time _____ min
    (**E**) Resulting Flow rate _____ gpm

Note: To reduce possible error, this comparative test will be performed simultaneously, whether the instrument used records in total volume (gal) per unit time or the standard (gpm) flow rate.

Equation for calculating correction factor of Permanent Existing Meter:

1 ÷ P/E = Correction Factor

where P=Permanent Existing Meter (gpm) and E= External Flow Meter (gpm)

Permanent Existing Meter Correction Factor (**PMCF**) = _____

If the flow changes due to control valves, variable RPM/speed pumps or other methods, repeat the process above to record those variable flows. These flows can be the maximum, minimum, and median flows expected to be used during typical water use conditions.

Flow condition 1 Max. Pump RPM or valve full open = _____   Q = _____gpm

Flow condition 2 Med. Pump RPM or valve half open = _____   Q = _____gpm

Flow condition 3 Min. Pump RPM or valve quarter open = _____   Q = _____gpm

PMCF (MAX) = _____

PMCF (MED) = _____

PMCF (MIN) = _____

If necessary, attach on separate page(s) all calculations, notes and photos to clearly identify the test site conditions and the obtained results shown above.

Note *(discovered problems)* _____

*(Recommendations)*_____

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad=portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

Ultrasonic Meter Method

For Non Metered Accounting Facilities
(See: Methods, Section C in Handbook)

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc) _____

Withdrawal type (ex. pumped, gravity, flow well, other) _____

Facility water use accounting method: _____

Flow Verification Information, Data and Calculations:

Ultrasonic Flow Meter used: _____
(manufacturer's make, model number)

Last calibration date of the Ultrasonic Flow Meter: _____

Test Site Information:

Pipe material tested_____

Pipe inside diameter _____inches

Pipe wall thickness _____inches

Transducer spacing _____inches

Test location: Distance from potential turbulent flow (ex. valve, elbow, etc.):
    (upstream) _____ (ft/in)
    (downstream) _____ (ft/in)

Ultrasonic Flow Meter reading:

Start Volume: _____gal

End Volume: _____gal

Elapsed test time_____min

Resulting Flow rate = _____gpm

If the flow changes due to control valves, variable RPM/speed pumps or other methods, repeat the process above to record those variable flows. These flows can be the maximum, minimum, and median flows expected to be used during typical water use conditions.

Flow condition 1 Max. Pump RPM or valve full open = _____   Q = _____gpm
Flow condition 2 Med. Pump RPM or valve half open = _____   Q = _____gpm
Flow condition 3 Min. Pump RPM or valve quarter open =_____   Q = ____gpm

If necessary, attach on separate page(s) all calculations, notes and photos to clearly identify the test site conditions and the obtained results.

The flow rate of each zone will be required for multiple zone systems.
If necessary, attach on separate page(s) all calculations, notes and photos to clearly identify the test site conditions and the obtained results.

Note *(discovered problems)* _____

*(Recommendations)*_____

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

VERTICAL PIPE METHOD
(See: Methods, Section C in Handbook)

General Permit Information Required:

Permit Number/App Number _____/_____

Project Name _____

Site Contact/Phone Number _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.) _____

Withdrawal type (pumped, gravity, flow well, other) _____

Facility water use accounting method _____

Flow Verification Information, Data and Calculations:

(SEE NEXT PAGE)

Reference Table for Flow from Vertical Pipes (gpm)

Pipe Inside Diameter (inches)	Rise of Water Spout Above Edge of Pipe (inches)										
	3	3.5	4	4.5	5	5.5	6	7	8	10	12
2	38	41	44	47	50	53	56	61	65	74	82
3	81	89	96	103	109	114	120	132	141	160	177
4	137	151	163	174	185	195	205	222	240	269	299
6	318	349	378	405	430	455	480	520	560	635	700
8	567	623	684	730	776	821	868	945	1020	1150	1270
10	950	1055	1115	1200	1280	1350	1415	1530	1640	1840	2010

Reference: Colt Industries, 1974

The flow (Q in gpm) through the pipe is calculated according to the formula:

$$Q = 5.68 \times K \times D^2 \times H^{1/2}$$

where:

K is a coefficient which ranges from 0.87 to 0.97 for pipes from 2 inches to 6 inches in diameter.
D = Pipe Inside Diameter (in)
H = Rise of water spout above edge of pipe (in)

Calculate Coefficient, K:

K = 0.87 for 2 in pipes and 0.97 for 6 in pipes as long as H is within 6 inches to 24 inches. Linear interpolation can be used to adjust K for pipe diameters between 2 and 6 inches.

(K) Calculation Example for a pipe with a 4-inch inside diameter:

$K_{4\ in\ pipe} = 0.97 - [(4 - 2) / (6 - 2)] \times (0.97 - 0.87)$
$K_{4\ in\ pipe} = 0.92$

Test Data:

K = _____
D = _____inches
H = _____inches

<u>Calculate Flow (Q) in Pipe (gpm):</u>

Q = 5.68 x K x D^2 x $H^{1/2}$

Q = 5.68 x _____ x _____^{2} x _____$^{1/2}$

Q = _____ gpm

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____

Company and Title: _____

Phone number: _____

Test Date _____

VOLUMETRIC METHOD
(See: Methods, Section C in Handbook)

General Permit Information Required:

Permit Number/App Number   _____/_____

Project Name _____

Site Contact/Phone Number   _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.) _____

Withdrawal type (pumped, gravity, flow well, other) _____

Facility water use accounting method _____

Flow Verification Information, Data and Calculations:

- Container Information (choose only one below):

    A. Weight Information:
    - ✓ Weight of Container when Empty (**E**): _____ lbs
    - ✓ Weight of Container when Full of Water(**F**): _____ lbs

    B. Volume Information:
    - ✓ Volume of Container when Full with Water (**Vgal**):_____ gallons

 Note!
The container must be large enough that it will take no less than 15 seconds to fill. The timing device must be a stop watch, capable of reading in at least 1/10 seconds.

If the flow is always constant because it is not controlled via a control valve, variable RPM/speed pump, or other method, do the following:

Measurement Information:

Measurement Number	Time to Fill Container (Seconds)
1	.
2	.
3	.
AVERAGE TIME (**T**)	.

(A) Weight

<u>Average Flow (gpm) from Pipe **Using Container Weight** Information</u>:

Weight of Water only in Container: (**F**)_____ lbs **–** (**E**)_____ lbs = _____ lbs

Water = 62.4 lbs / cubic feet (ft^3)

Volume of Water In Container (**Vft^3**): _____lbs / 62.4 lbs / ft^3 = _____ ft^3

7.48 gallons of water = one cubic foot

Equation:
Q = (**V ft^3**) **X** 7.48 gal / ft^3 **X** 60 sec/ min ÷ (**T**) sec
Where:
      Q = Flow rate (gpm) from pipe
      V = Volume of water (gal) in container
      T = Average time to fill container

Q =_____ gpm

(B) Volume

<u>Average Flow (gpm) from Pipe **Using Container Volume** Information</u>:

Equation:

Q = (**V**) gal **X** 60 sec/ min ÷ (T) sec
Where:
      Q = Flow rate (gpm) from pipe
      V = Volume of water (gal) in container
      T = Average time (sec) to fill container

Q =_____ gpm

If the flow changes due to control valves, variable RPM/speed pumps or other methods, repeat the process above to record those variable flows. These flows can be the maximum, minimum, and median flows expected to be used during typical water use conditions.

Flow condition 1 Max. Pump RPM _____or valve full open: Q = _____gpm

Flow condition 2 Med. Pump RPM _____or valve ____open: Q = _____gpm

Flow condition 3 Min. Pump RPM _____or valve___ open: Q = _____gpm

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

FLOW VERIFICATION (CALIBRATION) FORM

Weir Flow Method
(See: Methods, Section C in Handbook)

General Permit Information Required:

Permit Number/App Number   _____/_____

Project Name _____

Site Contact/Phone Number   _____/_____

District Facility ID _____
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.)

_____

Withdrawal type (pumped, gravity, flow well, other)

_____

Facility water use accounting method

_____

_____

Notice:

The following rectangular suppressed weir flow verification method is specific to flash-board riser type structures without end contraction. A Florida Registered Professional Engineer must verify that all the conditions shown in section C of this document (for this method) are applicable.

All other structures will require the submittal by a Florida Registered Professional Engineer of a flow verification/calibration plan, for approval by the SFWMD.

Flow Verification Information, Data and Calculations:

- **Name and number of Florida Registered P.E. :**

  _____

- **Attach photographs and or a site drawing that shows this structure meets the required conditions for the following test procedure.**

Weir Information:

Length of Crest, (L) = _____ft
Weir Elevation* = _____ft (reference)
Upstream Water Surface Elevation* = _____ft
Distance from the weir to the water surface elevation point = _____ft

* Important Note: Not necessary, if the height of water above the top of the weir can be measured directly.

Head on Weir (H):
H = the height of water above the top of the weir in inches ÷ 12 or;
        (Note, measurement must be to closest ½ inch)
 (Example: 9 ½ inches = 0.792 ft)
H = Water Surface Elevation (—) Weir Elevation
H = _____ ft

Weir Equation:

Q (ft³/s) = C x L, ft x (H, ft)$^{1.5}$
 Where the Weir Coefficient (C) = **3.13**
Flow (Q) = **3.13** X _____ ft X (_____ ft)$^{1.5}$

Flow (Q) = _____ ft³/s

Conversion from cfs to gpm:

Q = _____ ft³/s X 448.8 gpm/cfs
Q = _____gpm

After the flow verification is complete, inform the facility operator to begin logging (using a daily log book) the water used by this facility, via the water use accounting method described in the top section of this form.

At the end of each month, the facility operator will need to calculate, document and sum for each of his facilities, the total volume of water used, and record such monthly summary on the District's quarterly withdrawal form. The withdrawal form can be found in Appendix D of Section C in the handbook, and at the following web site:

http://my.sfwmd.gov/portal/page?_pageid=734,1456592,734_1456373&_dad =portal&_schema=PORTAL

Flow Verification Performed by (print name): _____
Company and Title: _____
Phone number: _____
Test Date _____

APPENDIX C

USEFUL CONVERSIONS AND MEASUREMENTS FOR LENGTH, AREA, AND FLOW:

PIPES AND CANALS/DITCHES

LENGTH, AREA AND FLOW CONVERSIONS

Length:
　　　1 foot (ft) = 12 inches (in)

Area:
　　　1 foot^2 = 144 in^2

Flow:
　　　1 cubic foot per second (cfs) = 448.8 gallons per minute (gpm)

CROSS-SECTIONAL AREA OF A PIPE
FLOWING FULL
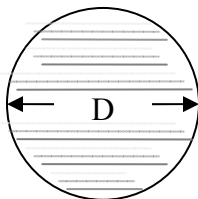
D = **Inside** pipe diameter

$$\text{Area} = \pi \times \left(\frac{D}{2}\right)^2 = \pi \times \frac{D^2}{4}$$

The Area will be expressed in ft^2 if D is measured in feet
The Area will be expressed in in^2 if D is measured in inches

CROSS-SECTIONAL WET AREA OF A PIPE FLOWING PARTIALLY FULL
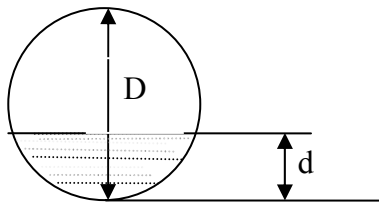
D = **Inside** pipe diameter   d = depth of water inside pipe

Wet Area = D² x Multiplication Factor

The Areas will be expressed in ft² if "D" and "d" are measured in feet
The Areas will be expressed in in² if "D" and "d" are measured in inches

Example   d = 3 inches, D = 8 inches

Multiplication Factor can be found from the table below as follows:

Calculate $\dfrac{d}{D} = \dfrac{3}{8} = 0.38$

Multiplication Factor for $\dfrac{d}{D} = 0.38$ is 0.2739 (see highlighted cells)

Wet Area $= 8^2 \times 0.2739 = 64 \times 0.2739$ in² $= 17.53$ in² $= 17.53/144 = 0.1217$ ft²

$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$	$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$	$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$	$\dfrac{d}{D}$	Multiplication Factor = $\dfrac{WetArea}{D^2}$
0.01	0.0013	0.26	0.1623	0.51	0.4027	0.76	0.6405
0.02	0.0037	0.27	0.1711	0.52	0.4127	0.77	0.6489
0.03	0.0069	0.28	0.1800	0.53	0.4227	0.78	0.6573
0.04	0.0105	0.29	0.1890	0.54	0.4327	0.79	0.6655
0.05	0.0147	0.3	0.1982	0.55	0.4426	0.8	0.6736
0.06	0.0192	0.31	0.2074	0.56	0.4526	0.81	0.6815
0.07	0.0242	0.32	0.2167	0.57	0.4625	0.82	0.6893
0.08	0.0294	0.33	0.2260	0.58	0.4724	0.83	0.6969
0.09	0.0350	0.34	0.2355	0.59	0.4822	0.84	0.7043
0.1	0.0409	0.35	0.2450	0.6	0.4920	0.85	0.7115
0.11	0.0470	0.36	0.2546	0.61	0.5018	0.86	0.7186
0.12	0.0534	0.37	0.2642	0.62	0.5115	0.87	0.7254
0.13	0.0600	**0.38**	**0.2739**	0.63	0.5212	0.88	0.7320
0.14	0.0668	0.39	0.2836	0.64	0.5308	0.89	0.7384
0.15	0.0739	0.4	0.2934	0.65	0.5404	0.9	0.7445
0.16	0.0811	0.41	0.3032	0.66	0.5499	0.91	0.7504
0.17	0.0885	0.42	0.3130	0.67	0.5594	0.92	0.7560
0.18	0.0961	0.43	0.3229	0.68	0.5687	0.93	0.7612
0.19	0.1039	0.44	0.3328	0.69	0.5780	0.94	0.7662
0.2	0.1118	0.45	0.3428	0.7	0.5872	0.95	0.7707
0.21	0.1199	0.46	0.3527	0.71	0.5964	0.96	0.7749
0.22	0.1281	0.47	0.3627	0.72	0.6054	0.97	0.7785
0.23	0.1365	0.48	0.3727	0.73	0.6143	0.98	0.7816
0.24	0.1449	0.49	0.3827	0.74	0.6231	0.99	0.7841
0.25	0.1535	0.5	0.3927	0.75	0.6319	1	0.7850

CROSS-SECTIONAL WET AREA OF
A CANAL/DITCH
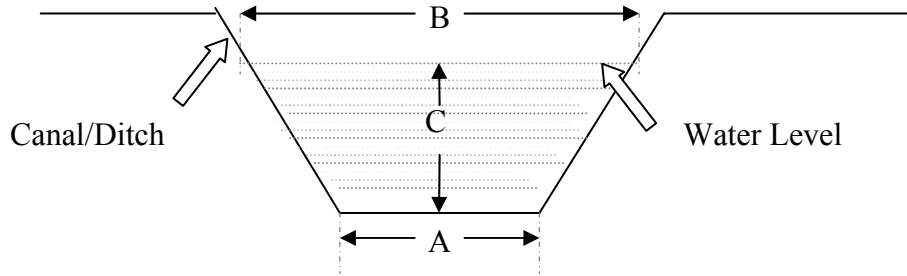
A = bottom width of canal/ditch (feet)
B = width of canal/ditch **at canal/ditch water level** (feet)
C = depth of water in the canal/ditch (feet)

Use the following formula to determine the cross- sectional area of water flow in the canal/ditch:

$$\text{Area} = (A + B) \times \frac{C}{2}$$

The Area will be expressed in ft^2 if A, B and C are measured in feet

SECTION D

Flowmeter Reference Guide

SECTION D

FLOWMETER REFERENCE GUIDE

TYPES OF FLOWMETERS AND BRIEF DESCRIPTIONS

Flowmeters are used to measure the flow of air, fluids, or gas. Most flowmeters are made up of three parts; the primary device, transducer, and transmitter. The three parts are often combined into one so the flowmeter may actually be only one instrument.

Some flowmeters measure the volume of the materials that pass through while others measure the speed, and still others measure the mass of the materials. Because of the varied uses, they are also used for a variety of fields. They are used for medical, plumbing, or industrial purposes. For industrial purposes flow measurement can help companies determine profit gain or loss.

Each type of flowmeter has specific guidelines that must be followed for proper use. For example, when using a flowmeter for gases the flowmeter must remain full of gas. The accuracy can be affected by liquid in the gas flowmeter. Similarly, in order for a liquid flowmeter to work properly it must remain full of liquid. Gas in a liquid flowmeter can affect the meters accuracy.

Quantity Meters – Measure isolated quantities of fluid through the primary element, either by weight or by volume. Known as positive displacement meters (except weighing meters and turbine meters). Considered to have higher accuracy than rate meters. Maintain good accuracy into the low flow range (except for turbine meter). With special secondary elements, sometimes used to measure rate.

1. **Gravimetric Meters (Quantity Meters)**

a. Weighers
- Involve weight determinations with a tank mounted on a beam scale (i.e. tilting bucket = 2 buckets fastened together and mounted over a pivot) (liquids)
- standard accuracy = 0.1%

b. Weigh belt
- for controlling the flow to maintain a constant predetermined rate of flow (i.e. a short conveyer mounted on scales or a short section of a longer conveyor supported by scales) (solids)
- standard accuracy = 1.0%

c. <u>Weight wheel</u>
- same as the belt, except for the belt being replaced by a fluted wheel
- advantage: the interval between the point where the flow is controlled and where the material is weighed is kept as short as practical to maintain more uniform flow
- standard accuracy = 1.0% (reading)

d. <u>Weigh dump</u>
- filling a container with a predetermined weight of material, then dumping, refilling and counting the number of times the container is refilled (solids)
- standard accuracy = 1.0% (reading)

2. Volumetric Meters (Quantity Meters)

a. <u>Metering Tank</u>
- elementary method
- repeatedly filling an open tank to a fixed depth and emptying it
- usually not as accurate as weighing
- chief advantage is low cost
- standard accuracy = 1% (reading)

b. <u>Nutating Disk</u>
- used for volumetric measurements of liquid
- commonly used for household water meters
- disk supported at the center by a ball, each cycle of the measuring disk displaces a fixed volume of liquid, single moving part in the measuring chamber is the disk, advancing volume of liquid moves the disk in a nutating motion until liquid discharges from the outlet port, movement is used to rotate a shaft which drives a counter to indicate the quantity of liquid passed through the meter
- simple design, low cost and maintains high accuracy over long periods of use
- standard accuracy = 1% (reading)

c. <u>Gear or Lobed Impeller</u>
- similar to gear pump
- in lobed impeller meter: measuring chambers are the spaces between the lobes and the meter housing, impellers are kept in their proper relationship to each other by spur gears outside of the fluid chamber, the clearances between the rotors and case and between the rotors themselves, can be made very small, therefore obtaining effective capillary sealing of the measuring chambers, by use of precision bearings the overall pressure drop can be kept low
- used more extensively for measuring gases than liquids
- standard accuracy = 1% (reading)

d. <u>Sliding Vane Readings</u>
- operates similar to vane pump

- the vanes slide through a slot in the rotor to the meter housing isolating a portion of the fluid, and the pressure of the incoming fluid causes the rotor to rotate, the in-and-out movement of the vanes is controlled by a cam in the rotor shaft, vanes should not actually touch the meter housing, should maintain a close tolerance (to prevent the fluid from escaping around the vanes), friction in meter can be kept small (with low friction bearings), therefore low pressure loss
- a different version of the machine does maintain continuous contact with the cylinder walls by using a spring-loaded sliding vane (improves the seal, but sacrifices the low-pressure-drop advantage)
- standard accuracy = 1%

e.   Rotating Vane
- operates similar to sliding vane except vanes are curved (semicircular) and are rotated into proper contact position with chamber walls by gears
- standard accuracy = 1%

f.   Dethridge Meter
- special application of the vane-type meter
- widely used in Australia and New Zealand to measure irrigation water flows and almost unknown in US
- weight is approximately 80 kg (176 lbs)
- simple and robust device to measure water volumes passing onto land for irrigation
- it turns around when the channel water flows underneath it, volumes passed are recorded in Megaliters (ML) on an inbuilt revolution counter and customers are charged accordingly, by timing the speed of wheel rotation, flow rates in ML/day can be easily calculated
- accuracy depends on calibration of similar devices
- errors occur from excessive bottom clearances (std clearance = 5 mm) and operating below 150 L/s
- standard accuracy = 3% (full scale)

g.   Reciprocating Piston
- most accurate positive displacement meter
- more expensive and causes a relatively high pressure loss
- essentially a reciprocating piston engine, except the meter extract only enough energy from the fluid passing through it to overcome the frictional resistance in valves and register (the engine is designed to extract as much energy as possible)
- many different types: sing-acting, double-acting, multi-pistons, pistons is a single plane, and parallel pistons
- standard accuracy = 1% (reading)

h.   Oscillating Piston

- consists of 3 cylinders, smallest is approx. ½ the diameter of the largest, with the remaining cylinder having a diameter midway between the former two
- cylinders are nested with the inner and outer cylinders rigidly and concentrically connected by a partition running the full length of the cylinders
- entrance and exit ports in the cylinder caps are shaped so that incoming fluid cannot enter the same chamber that is discharging
- flow is nearly continuous
- best suited to clean water because sand grains can jam the mechanism due to the close tolerances
- standard accuracy = 1% (reading)

i.   Diaphragm or Bellows Meter
- used for measuring gases
- standard accuracy = 1% (reading)

Rate Meters – infer a readout from a continuous stream that moves through the primary element. May generally be classified according to the physical property or properties exploited in the flow rate measurement.

3. **Differential Meters (Rate Meters)**
- most can be constructed with common shop equipment
- chief disadvantages are a large head loss and necessity of pressure taps
- accuracy is affected by changes in density, temperature, pressure, viscosity and by pulsating flow
- accuracy should be between 1 and 2%.
   a. Venturi Tube
   - does not have a frictional head loss to produce the difference in head, therefore the fluid velocity can be determined closely from theoretical considerations
   - consists of a reduced cross-section in a pipeline, designed so the fluid flows through the venturi with a minimum of pressure loss
   - flow is determined by measuring the change in static pressure from the large pipe cross-section to the small pipe cross-section, difference in these pressures is equivalent to the increase in velocity going from large pipe diameter to smaller pipe diameter; used where accurate flow measurement must be made with minimum loss of energy; venturi is quite long
   - usually considered to be a permanent installation
   - recommended for clean fluids
   - can be used for control applications where accurate rate measurement is not required
   - standard accuracy = 1.5% (full scale)
   b. Twin-Throated Venturi
   - has rounded shoulders inside instead of the sharp orifice-like edge
   - this modification should make the meter suitable for dirty fluids

- standard accuracy = 1.5% (full scale)
  c. Orifice Meter
    - a conduit and a restriction to create a pressure drop (ie: an hour glass)
    - most of the marketed differential-head meters are sharp-edged concentric orifice plates
    - advantages of orifice plate: simplicity and the ability to select a proper calibration on the basis of the measurements of the geometry
    - disadvantages: long straight pipe length requirements and the complication of extending the measuring range beyond a ratio of about 1:3
    - standard accuracy = 1.5% (full scale)
  d. Rectangular Orifice (Open-Channel Applications)
    - rectangular orifices formed by a partly-open, irrigation slide gate are frequently used as flow-indicating devices
    - high accuracies are not to be expected due to the irregularity of gate frame slides and the different bottom edge treatments of gates
    - however, accuracies to within + or − 5%, not including the errors of depth detection, can be approached
  e. Flow Nozzle
    - consists of a flared inlet section followed by a cylindrical throat that is usually between 0.25 and 0.7 of line diameter
    - handles dirty fluid well
    - is more accurate for high velocity flow
    - gives better pressure recovery and is less susceptible to inaccuracies resulting from wear than the orifice
    - more expensive and more difficult to remove from the line than the orifice
    - standard accuracies = 1.5% (full scale)

  f. Centrifugal Flow Element
    - flow can be measured by using the centrifugal force developed in a circular loop
    - accuracy is about 2% when using theoretically determined coefficients
    - better accuracy can be obtained by individual calibration
    - the 90 degree elbow as a primary element for a flowmeter using this principle is one of the easiest elements to construct
    - advantage: replacing an existing elbow and the ability to measure flow in either direction without contributing additional head loss to the piping system
    - when calibrated in place, its accuracy is comparable to that of the venturi and orifice meters
    - without calibration in place, accuracy is about + or − 5%
    - standard accuracies = 1.5% (full scale)
  g. Pitot Tube
    - one of the oldest basic devices for measuring velocity

- commercial application is limited because the range of rates that can be measures is quite narrow and the variations in velocity profiles in pipes are quite wide
- uses the difference between the kinetic and static pressures at a point in the flow
- consists of 2 members
  - one, "total-head probe", indicates the sum of the static and velocity, or impact pressures, at the tip of the probe; total pressure is sometimes referred to as stagnation pressure
  - second member indicates only the static pressure and may be a wall tap in the conduit to complement the use of elementary pitot tubes
- major limitation in the use of pitot tubes is in the devices that must accurately determine the flow pressure differential produced at low fluid velocities
  - 2 alternatives to this large, slow response have been suggested and successfully used
- although it performs properly at very low velocities, the sensitivity of the manometer gage usually used with the pitot tube is insufficient to measure velocities of under 2 m/s of air flow
- standard accuracies = 2% (full scale)

h. Linear Resistances
- primary elements of this flowmeter consists of a series of very small openings (usually a thin slot of capillary) through a corrosion-resistant material (is: stainless steel)
- when the Reynolds number of the fluid flowing through the openings is kept less than 1000 so that viscous forces predominate, the flow will be directly proportional to the pressure drop across the element
- can be designed and calibrated for high accuracy
- can be used for liquids but is usually not because of the large changes in viscosity as a function of temperature
- the flowing gas must be kept clean to prevent clogging of the small slots
- since the measurement is dependent on viscosity, each gas requires a separate calibration curve
- flow ranges are available from about 0.1 mL/s to more than 100 mL/s
- the pressure loss is relatively high
- since it is a resistance device, there is no pressure recovery
- standard accuracy = 1% (full scale)

4. **Variable Area Meters (Rate Meters)**
- operate by means of differential pressure
- maintain a relatively constant differential pressure and change the aperture area in response to flow rate (unlike head meters which contain a fixed aperture and produce a variable differential pressure)

a. **Glass Tube Rotameter**
- most common device of this type
- vertical, tapered glass tube containing a movable weight
- amount of cross-sectional area is determined by height of the weight as it is suspended by the force of pressure
- differential pressure remains constant except for friction
- as flow is increased, the weight is forced higher in the tube causing the area to increase
- tube is graduated so that flow rate can be read directly on a scale
- accurate over a wide range, including low flow rates
- individual calibration may improve accuracy
- pressure loss is small
- not satisfactory for fluids containing solids
- glass tube must be kept clean and the meters should be kept within 2 degrees of vertical for proper operation
- standard accuracy = 1.5% (full scale)

b. **Slotted-Cylinder and Piston**
- used for measuring the flow of liquids (particularly highly viscous, opaque fluids)
- the liquid enters a vertical cylinder with a close-fitting, weighed piston that is forced upward until sufficient port area in the cylinder wall is available to pass the fluid
- a shaft on the piston forms the armature of a coil
- changes in the vertical position of the piston change the impedance of the coil to indicate the rate of flow
- standard accuracy = 1% (full scale)

5. **Variable Head and Area Meters (Rate Meters)**
- these meters find wide use in open channel measurement
- are usually a type of weir or flume
- require a free surface, therefore they are applicable only to liquid flows, usually water
- unless meticulous maintenance procedures are practiced, vegetation growths in the channel, accumulations of trash and silt near the primary element, and deterioration of the primary element from corrosion or algae growths on the surface make accuracies of better than + or – 5% doubtful
- measurements of flow depths accurate to more than + or -1 to 2 mm are not warranted
- under lab conditions, the devices can be accurate better than + or – 2 %
- weirs and flumes convert potential energy to kinetic energy to cause critical flow

  a. **Sharp-Crested Weir**
  - one of the oldest of the open channel devices
  - the weir is one of the simplest and most accurate means of measuring flow of water in channels when conditions are favorable

- rectangular weir is most popular because it is easy to construct and accurate when used properly
- 90 degree V-notch weirs have an important advantage in that they have a larger range in capacity for each size than rectangular weirs
  - normally restricted to flow rates less than 100L/s because the required difference in elevation between the upstream and downstream channel water levels become large
- trapezoidal or Cipolletti weir is similar to rectangular weir
  - has sides that slope at the rate of one horizontal to four vertical
  - more nearly independent of approach velocities
- side-suppressed weirs contract only from the bottom
  - width is the same as the channel
  - flow can change appreciably with small changes in water surface elevation depending on the amount of bottom contraction and the resulting velocity of approach
- the edges of a weir should be sharp, thin, and smooth on the upstream side
- discharge (nappe) from the weir opening should be free and the undernappe should be ventilated to prevent forming a low pressure area
- portable steel weirs are available and can be moved from one location to another
- chief disadvantage of weirs: requirement for large head losses and poor silt carrying capacity
- the usual recommendation is that the downstream water surface be at least 50 mm below the crest of the weir opening
- standard accuracy = 1.5% (full scale)

b. Short-Crested Weirs
- two most common examples: V-notch weir sill and Crump weirs

c. Short-Throated Flumes
- examples: Parshall flume and the Cutthroat flume
- Parshall flume
  - commonly found throughout irrigation projects
  - causes a relatively small loss of head
  - carries silt well
  - is not seriously affected by approach conditions
  - often a permanent structure made of concrete
  - portable versions are usually made of steel or fiberglass
  - flow rates can be measured from 1 L/s for a flume with a 76 mm throat to 5 m^3/s with a 3 m throat
  - accuracy is considered to be + or – 5%
- Cutthroat flumes
  - head loss characteristics are similar to those of the Parshall flume
  - hydraulic behavior is complex

- o careful installation is required for accuracy
- standard accuracy = 3% (full scale)
  d. Long-Throated Flumes
  - also called "computables" because their construction specifications are such that parallel, non-curvilinear flow is produced in almost any size and cross-sectional shape
    - o allows accurate predictions of their hydraulic behavior without laboratory ratings
    - o permits estimating the effects of construction anomalies
  - advantages
    - o conformance to standard sizes or shapes is not necessary; they can be shaped so that all practical ranges of discharge can be measured accurately
    - o rating tables can be calculated with an error in the listed discharge of less than 2%
    - o required head loss over the structure is low and can be calculated
    - o for similar hydraulic conditions they are usually the most economical for accurate flow measurements
  - standard accuracy = 2% (full scale)
  e. Movable-Crested Flume
  - special adaptation of the long-throated flume
  - can be conveniently used in portable version for flows less than 100L/s
  - in larger versions with mechanical lifters it can also serve as a gate structure when completely raised
  - several field-user conveniences are incorporated

6. **Force Displacement Meters (Rate Meters)**
   - related to the variable-area meters in that both operate by a force displacing an obstruction immersed into the flowing fluid
   - force is allowed to vary and the flow area remains essentially constant
   - the force, which is caused by the impact of the fluid on the obstruction, causes a deflection of the primary element
   - a measure of this displacement is a function of the differential pressure and serves to indicate the flow rate
   - simple designs and most do not require external power
   - chief advantage: elimination of the pressure taps common to other differential meters
   - pressure loss is comparable to that of the orifice or the nozzle
   - ball and variable weight flowmeters can not be bought commercially but can be built
     a. Target Meter
     - force meter
     - primary element is similar to the sharp-edged annular orifice and is mounted on a support passage through the pipe wall

- deflecting force of the member caused by the differential pressure acting on the target is measured with a strain gage or similar measuring device
- target meter with strain gage has good accuracy
- standard accuracy = 1% (full scale)

b. Vane
- primary element is a hinged vane
- fluid flow is proportional to the angular position of the vane
- has some characteristics of differential-pressure and area meters
- meters in which the vane is weighted must be mounted horizontally
- meters in which the vane is spring-loaded do not necessarily need to be mounted horizontally
- standard accuracy = 1% (full scale)

c. Ball
- consists of a section of transparent tubing bent into a semi-circular arc
- primary element is a ball placed in the curved tub
- the differential pressure which occurs across the ball supplies a force to support the ball part way up the curved portion of the tubing
- angle between the line passing through the ball and the center of curvature of the tubing and a vertical line is the index of flow
- standard accuracy = 2% (full scale)

d. Variable Weight
- consists of a vertical transparent pipe with a float in the pipe
- float has a density less than that of the fluid
- a chain is fastened to the bottom end of the float
- as flow increases upward, the float rises and supports a larger portion of the chain; therefore, the effective weight of the float also increases
- the float reaches an equilibrium point where the force due to the differential pressure across it is balanced by the load on the float form the chain
- standard accuracy = 1.5% (full scale)

e. Hydrometric Pendulum
- sometimes used to determine flow velocities in open channels
- simplest form: consists of a ball, with a density greater than that of the flowing fluid, suspended by a string
- the angular deflection of the ball and string is proportional to the velocity of the flow near the ball
- only approximate since fluctuations of the stream flow make accurate determination of the defection angle difficult
- principal cause of unsteadiness of the ball and string is the formation of alternating eddies on the downstream side of the ball
  - similar to the "von Karman vortex street" caused by a cylinder in a uniform flow
- standard accuracy = 5% (full scale)

f. Pendvane
- patented device
- combination of the hydrometric pendulum and the simple vane meter
- designed for use in open channels and is most commonly used on small ditches less than 3 feet deep and 6 feet wide
- indicates flow directly
- deflection is measured by a bubble in a specially curved tube mounted on the vane (marked directly in ft^3/s)
- a special vane is available for each of a variety of rectangular and trapezoidal ditches
- accuracy is + or – 5% depending on the flow range, but errors of + or – 10% are frequent
- standard accuracy = 3% (full scale)

g. Integrating Float
- involves rising spheres released from the stream bottom
- during their rise the spheres are displaced downstream in the direction of flow and give an integrated response to the velocity profile through which they ascended
- several difficulties in using this method
  - i.e.: how do you determine the accurate spot of surfacing?
- accuracy is about + or – 5%
- this technique is not too unlike some studies of air currents made with rising weather balloons
- standard accuracy = 5% (reading)

h. Jet Deflection
- fluidic velocity sensor utilizes a free jet directly deflected by the measurement flow
- directed from a nozzle toward two total head tubes
- measured flow displaces the jet, producing a pressure difference between the two head tubes
- response is nearly linear
- particularly useful in air velocities below 20 ft/s and water velocities below 0.3 m/s
- standard accuracy = 5% (full scale)

7. **Force Momentum – Mass (Rate Meters)**
   a. Axial Flow Mass Meter
   - includes a turbine driven at a constant speed to induce a constant angular velocity to the fluid and a similar spring-retained turbine rotor to measure the force required to overcome the angular momentum
   - angular displacement of the retained rotor is directly related to the mass flow of the fluid

- in some designs the turbine is driven by magnetic induction and the deflection of the spring-retained turbine is determined in a similar manner
  - this eliminates the need for rotating seals
- most common: axial-flow, transverse-momentum mass flowmeter
- primarily designed to measure the mass flow of liquid fuels
- standard accuracy = 0.5% (reading)

b. Radial Mass Meter
- commonly called the "Coriolis" mass flowmeter and has a primary element resembling a centrifugal pump
- fluid is accelerated radially and the torque required to accomplish this is proportional to the mass flow of the fluid
- meter will measure flow in either direction
- handles gases, liquids, foams, and slurries
- produces pressure rise rather than pressure drop
- is adaptable to standard recording, indicating, and controlling equipment
- standard accuracy = 1% (full scale)

c. Massometer
- granular material moving down in a vertical pipe is accelerated in a horizontal plane by means of an impeller driven by synchronous electric motor
- torque required of the motor above that needed to overcome friction is proportional to the material passing through the meter
- accuracy is + or − 1%
- maximum flow is as high as 200 lbs/minute
- standard accuracy = 1% (full scale)

d. Magnus Effect
- phenomenon that produces a differential force on a smooth-surfaced cylindrical body rotating in a moving fluid
  - this is the force that causes a spinning ball to travel in a curved path
- force is proportional to the density and velocity of the fluid and the surface speed of the rotating body
- mass flow is a linear function of the differential pressure
- it is necessary that the velocity of the fluid on either side of the cylinder be the same when the cylinder is not rotating
- requires rotating seals and a constant-speed drive
- standard accuracy = 1% (full scale)

8. **Force Velocity Meters**
- usually use a turbine or propeller to sense the flow of a moving fluid
- chief difference between the turbine and the propeller meters is the design of the blades and rotor
- propeller
  - normally has only a few large curved blades

- o meters are generally used for large pipes
  - o meters produce less pressure loss but do not function as well as turbine meters at high flow velocities
- turbine
  - o has many small blades, with less curvature
- characteristics and properties of both meters are similar
  - a. Turbine Flowmeter
    - available in more variations than any other mechanical meter
    - used widely in pipeline applications (particularly for hydrocarbons) but are limited by bearing durability and friction
    - require regular calibration to ensure good performance
    - poor accuracy at low flow, but performs well at high flow rates
    - in most designs the rotor drives a counter to indicate directly the total quantity of fluid having passed through the meter
    - instruments of high accuracy, fast response and wide versatility under extreme operating conditions
    - take up little space in the pipe line and the turbine wheel is small and light weight to maintain good response speed
    - recent developments include twin rotor designs; two designs are particularly successful
      - o one – by Quantum Mechanics – has two rotors with independent sets of bearings; because friction is very low the fluid is not required to accelerate past the rotor to obtain sufficient torque to overcome retarding forces
      - o second (the Auto Adjust turbo-meter) – by Rockwell International – is both self checking and self adjusting; two rotors are used; they are next to each other with the measuring rotor downstream from the main rotor
    - to eliminate spiraling of the liquid as it reaches the rotor, it is recommended either that turbine meters be preceded by a length of straight pipe or that straightening vanes be used
    - a turbine meter should be calibrated with the liquid in which it will be used
    - not suitable for liquids containing solids
    - presence of entrained air causes an error
    - standard accuracy = 0.5% (reading)
  - b. Turbine Compound
    - this design overcomes the loss of accuracy of the turbine meter at low velocities
    - a turbine meter is placed in parallel with a low-capacity, positive displacement meter

- a valve controls the flow such that at low flow the liquid passes through the positive displacement meter and at high flow the fluid is directed through the turbine
- standard accuracy = 0.5% (reading)

c. Propeller Meters
- introduce small pressure losses
- handle higher flow rates than positive displacement meters but lower flow rates than turbine meters
- used in pipe lines, water mains, and high-flow applications that require a low permanent pressure drop combined with a mechanical output
- type of propeller meter: current meter
  - frequently used in open channel flow
  - recognized as the standard instrument to measure the discharge of rivers and canals
  - small instrument containing either a revolving cup-type wheel or propeller that is turned by movement of the water
  - normal procedure is to divide the cross-section of the stream into increments of the same width at a section of the stream free from obstructions
  - the current meter is located at the center of each increment
  - total flow of the stream is the sum of the products of the average velocities times the area of the respective increment
- flow in open streams can be measured by calibrating the stream bed
- standard accuracy = 1% (reading)

d. Aerovane
- frequently used to measure wind speed and consists of a propeller mounted on a horizontal axis
- housing incorporates a direction vane to keep the propeller facing into the wind and indicates direction with the same element
- more expensive than the cup anemometer (see description below) and is generally regarded as a better instrument
- standard accuracy = 1% (reading)

e. Vortex Velocity Meter
- consists of a conduit having an enlarged section
- flow through the conduit results in a vortex pool being set up in the enlarged section of the conduit
- a vortex cage located in the vortex counts the revolutions of the vortex pool
- meter is accurate, sensitive, and very low pressure loss
- standard accuracy = 0.5% (reading)

f. Cup-Type Meter
- primarily used for open channel flow

- when designed for open channel flow, they are referred to as current meters, but this term also includes a variation in design that uses a propeller instead of cups
- independent of flow direction in a horizontal plane
- when cup-type meters are used for air flow measurement they are called "cup anemometers"
    - for wind velocity, the cup anemometer has been the standard method in the Weather Bureau for over 50 years
    - instrument has high reliability
    - rotates about a vertical axis with usually 3 or 4 conical cups having rolled, or beaded, edges
    - a high moment of inertia causes the anemometer to lag when the velocity is increasing and coast when the velocity is decreasing
    - special designs are available with low moment of inertia and low friction to provide a starting velocity as low as 0.1 m/s yet sturdy enough to measure 25 m/s winds and fast enough to indicate the velocity of gusts
- standard accuracy = 1% (reading)

g. Float Velocity
- this technique places one or more floats in a stream and measure the time required for the float to pass from one line across the stream to another line a known distance downstream
- depending on the size of the float, the velocity obtained will need to be multiplied by a factor
    - a small float near the surface will travel faster than the average stream velocity and must be multiplied by a factor of 0.6 to 0.9 depending on channel depth and other factors
    - a long, narrow float weighted at one end so it floats vertically downstream will travel at about the average velocity of the stream if it is about 0.9 the depth of the stream
- float techniques are not very accurate
- standard accuracy = 5% (reading)

h. Chemical Velocity
- similar to the float method
- uses a salt, radioactive tracer, or dye injected into the stream
- the time of passage between two points along the stream can be detected accurately using suitable electronic equipment
- since dispersion spreads the tracer considerably, the peak concentration is usually used as the reference point although the center of gravity of the passing wave is theoretically better
- accuracy depends somewhat on the detecting equipment, but can be on the order of + or – 1 to 2%

- method is most suited to closed conduits and prismatic channels since flow are is necessary to determine discharge rate
- should not be confused with chemical dilution techniques (see below for description)
- standard accuracy = 1.5% (reading)

9. **Thermal Meters (Rate Meters)**
   - originally developed for gas flows
   - now available in many forms for the measurement of fluid flows
   - especially valuable for the study of turbulence structure in both gases and liquids
   - operate on the principle that heat is absorbed by a flowing stream in proportion to the rate of flow
   - mass flow is actually indicated and is measured by introducing a known amount of thermal energy, instead of mechanical energy, into the fluid stream
   - less expensive than other mass flowmeters, but are not independent of temperature, composition, viscosity, etc.
   a. Hot Wire Anemometer
      - based on the variation in resistance of an electrical conduit with conduit temperature and the variation of the conduit temperature with the velocity of a gas past the wire
      - the temperature may be held constant while measuring the current or the current may be held constant while measuring the resistance of the wire
      - for high velocities (i.e. 800 ft/s) the temperature of the wire is usually about 1800 degrees F
      - for low velocities (less than 10 ft/s) a much lower wire temperature must be used
      - important factors that affect the accuracy are:
        o ambient air temperatures exceeding the range for which the instrument was calibrated
        o specific heat of the air or gas
      - standard accuracy = 1.5% (reading)
   b. Hot Film Anemometer
      - principle is similar to the hot wire in operation
        o hot film is more suitable for liquid flows than the hot wire
      - quartz-coated hot film sensors are available that provide good stability for flow measurement in gases and electrically conducting fluids, such as water, and can operate from steady state to frequencies of 35,000 Hz
        o special sensors are available to 50,000 Hz
      - these devices are attractive for the study of turbulence in liquids
      - main disadvantages
        o high cost of the auxiliary equipment or secondary devices
        o fouling of the tip in dirty fluids

- standard accuracy = 1.5% (reading)
c. Thermocouple Anemometer
  - has a hot and a cold thermocouple junction
  - heat input to the hot junction is kept constant and the temperature difference between the two junction is inversely proportional to the velocity of the air past the junctions
  - hot wire anemometer and the thermocouple anemometer can be used to measure very low air velocities in the order or 30 mm/s
    - difficult to make accurately
    - presence of the observer may materially affect the measurement
  - thermocouple measures the velocity at a point
  - like the pitot tube, flow rate is influenced by the velocity distribution
    - this distribution will not cause a serious error if viscosity, density, and conduit diameter are essentially constant and the meter is calibrated under the conditions that it will be used
  - instrument measures mass flow accurately as long as the product of thermal conductivity, specific heat at constant volume, and density are constant
  - normally this product is constant over a wide range of temperature and pressure
  - pressure loss caused by the primary element is small
  - standard accuracy = 1.5% (reading)
d. Thomas Meter
  - this flow-metering method is commonly used for measuring the mass flow of gases
  - in operation a heater adds a small amount of energy to the flowing stream
  - if the heat input is held constant, the temperature rise is inversely related to the mass flow of the gas
    - if the temperature rise is held constant, the heat input required to maintain that condition will be directly related to the mass flow
  - not normally used to measure the flow of liquids because an excessive amount of energy is required to secure a satisfactory temperature rise, but the pressure loss is small
  - accurate and has good sensitivity
  - standard accuracy = 1% (reading)
e. Boundary Layer Mass
  - the heater and temperature-measuring elements are on the outside of the conduit
  - with this design, just the layer of fluid immediately adjacent to the inner wall of the conduit is heated
    - liquids can be handled with a reasonable expenditure of energy
  - good response time of less than a second can be obtained with careful design
  - this requires:

- o keeping the distance that the energy must travel from heater to fluid and from fluid to temperature-sensing element as short as practical
  - o using a conduit material of low specific heat
  - o using adequate external insulation
- there is no obstruction in the stream so the meter causes no more pressure loss than a similar section of straight pipe
- a special circuit normally used to make the output linear and an automatic temperature-compensating device can be used
- power requirement is about 1 W/ 10 kg/s
- changes in composition of the fluid can cause an error
  - o if these changes are known, a correction can be made
- accurate and has a wide flow range
- standard accuracy = 1% (reading)

10. **Chemical Dilution Techniques**
    - transcends many of the difficulties that beset other discharge measurement methods
    - applicable to any kind of conduit, open or closed
    - does not involve stream dimensions or measurement of fluid levels or pressures
    - does not require:
      - o a pressure loss
      - o a drop in hydraulic head
      - o impediment to the flow
    - indicates flow rate directly by simple theoretical formulas
    - method is especially attractive for gaging natural streams
    - radioactive tracers and fluorescent dyes have greatly reduced the quantity of chemical required for accurate quantitative measurements
    - fluorescent dyes, especially Rhodamine WT, can be quantitatively detected in stream flow samples in concentrations of less than 10 ppb with an accuracy of approximately + or – 1% using modern fluorescent assay equipment
    - two general methods are discussed below
    - a. Continuous Addition of Tracer
      - q = the rate at which the tracer is injected into the stream (known)
      - C = concentration of the injected tracer (known)
      - Q = stream flow rate to be determined (unknown)
      - C = resulting concentration of the tracer combined with the stream (measured)
      - q*C = (Q + q)*C   ((solve for Q))
      - method is suited to the measurement of irregular streams where numerous and extensive eddy cavities retard the turbulent mixing process
        - o if the injection period is extended long enough, the effects of isolated eddy cavities in the stream bank are neutralized and accurate flow rate determinations are possible

- method depends directly on the accuracy of the tracer injection rate and the assay of the sample collected
- standard accuracy = 2% (reading)

b. Slug Injection Method
  - requires a steady state rate of sampling during the entire passage of the tracer wave (this rate need not be known)
  - the total amount of tracer being injected is weighed, rather than trying to determine an accurate rate of injection which is much harder
  - can be applied to pipes and man-made canals where large eddy cavities are not present in great numbers
  - slug of tracer is rapidly poured into the stream
  - as the tracer wave is carried downstream it becomes increasingly dispersed
  - at some station at distance x, the rate of change of the tracer concentration passing the sampling station becomes so small that the corresponding lateral gradient results in negligible differences in the tracer wave at the center line of the stream and near the stream bank
  - since dispersion only changes the distribution of the tracer, not the total amount of it, the time-concentration curve at a downstream station is monitored
  - the tracer passing the monitoring station in a channel with steady flow must equal the quantity, S, added as some upstream station
  - $S = Q \int (c \, dt)$ ((where the integral is from 0 to t))
  - plot of time versus concentration can be developed from a series of individual samples taken as the tracer wave passed the monitoring station
  - it is more practical to simply remove a continuous sample from the stream at a uniform rate for the entire time needed to pass the tracer wave
  - this entire sample is stored in a tank and thoroughly mixed at the end of sampling
  - this effectively integrates the area under a time-concentration curve giving the average concentration of this combined sample
    - the discharge computation becomes:
      - $Q = S / (\text{average } c * \Delta t)$
        - where t = total time of the sampling period
  - continuous addition and slug injection are similar
    - both require transverse missing, the determination of tracer concentration of a single sample, and can theoretically be manipulated to require similar quantities of tracer materials
  - standard accuracy = 2% (reading)

11. **Special Metering Methods**

<u>Electromagnetic Flowmeters</u>

Also called magnetic or electromagnetic meters, they offer an excellent solution to problems of flow measurement in conductive liquids. They have recently become widely accepted in industry because of their many advantages including:

- o no moving parts
- o head loss equal to that of a similar length pipe
- o accurate measurements over wide flow ranges

The measuring principle is based on Faraday's law of electromagnetic induction. Because this flowmeter measures the entire cross section of the flow tube, its reading is independent of the flow profile. This eliminates concern over fluid viscosity or density and reduces the pipe length requirements the typical accuracy is between 0.5% and 1.0% over a wide range. They come in a variety of shapes, sizes and materials of construction. This is one of the meters least affected by the velocity profile in the pipe. It should be installed with straight runs of pipe on each end in order to obtain stated performance and long life. The typical straight-run requirements are 3 to 5 pipe diameters upstream and downstream. The user should follow guidelines of the manufacturers. An electromagnetic flowmeter is offered for waterworks and irrigation applications. It is a pulsed DC type with polyurethane liner. It is available for pipe sizes from 1 inch to 12 inches. It is configured to operate on 24 volts DC battery. It claims less than 25 VA power consumption, + or − 2% of rate accuracy, durability, and moderate capital investment. The pipe sidewall-insertion probes are about 30 mm in diameter with implanted magnetic coils and sensors are commercially available. These probes are subject to velocity profile limitations. The standard accuracy = 1% (full scale).

b. <u>Ultrasonic</u>
- two basic systems using ultrasonic waves
  - o the Doppler
  - o the transit time meter
- two systems operate on completely different principles
- modern clamp-on transit-time meter can indicate flow rate to better than + or − 2% of reading, depending on design
- Doppler meters usually indicate no better than + or − 5% of full scale reading
- major advantage: negligible head loss and the ability to install either portable or dedicated systems without line shutdown
- recent improvements have removed most of the earlier limitations so that today Doppler meters are operating in nearly clear liquids and transit-time versions are handling coal slurries
- developments are aimed toward using the processes in gas flows
- ultrasonics are applied to flowmetering in 2 basic ways, resulting in 2 basic meter types:
  - o transmission

- establishes a sound path through the liquid in the pipe of channel
  - o reflection (Doppler)
    - depends on particles in the fluid that can reflect sound to the receiver
    - is really just another way to detect particles in the fluid
- standard accuracy = 1% (full scale)

c. Ultrasonic Time-of-Flight Meters

- multiple beam systems have been installed on many pipelines, the most notable of which is the Alaskan oil pipeline
- have become popular for measurement of flow in large pipelines in irrigation distribution systems
  - o have also been used in some canal systems
- several paths of sonic beams are sent across the flow area at an angle to the flow velocity
  - o flow must be relatively free of suspended materials that could reflect and spread the sonic energy
  - o in pipes with diameter greater than one meter, four paths across the full pipe are commonly used
- meters are relatively expensive, require an electric power source and trained technicians for assured operation
- this type requires at least 2 transmitters and 2 receivers
- 2 sound paths are established in the fluid, usually along the same diagonal path but in opposite directions
  - o on one path, the sound travels with the direction of fluid flow at an angle across the flow
  - o on the other path the sound moves against the direction of fluid flow
- the motion of the fluid causes a frequency shift in each path

d. Ultrasonic Doppler Meter

- Doppler, or reflective type meter also works on a frequency-shift principle
- frequency shift occurs in the sound reflected from particles that are presumed to be moving at the same velocity as the fluid itself
- latest versions operate with particle sizes below 100 micron and at a concentration of 100 parts/million or less
- theory is based on the assumption that the Doppler shift is inversely proportional to the velocity of the particles in the liquid:
  - o F = Doppler shift
  - o v = velocity of the fluid
  - o f = broadcast transmission frequency
  - o Φ = angle of entry of the broadcast transmission beam
  - o C = velocity of sound on the specific fluid medium
  - o $F = (v*f*\sin\Phi)/C$
  - o corrections are required for the effects of velocity-profile

- Doppler performance is limited in particular situations by:
  - spatial resolution
  - spectral broadening, due to transit time effects for scattered reflections, velocity gradients, finite beam width, non-axial flow components such as turbulence
  - distribution of scattering particles
  - non-uniformity of interrogation beams
  - non-uniform weighing factors due to attenuation
  - path ambiguity in severe velocity gradients
- meters may need to be calibrated after installation
- frequently, problems occur when installed on pipes that have liners, or on rough fiberglass or cast iron pipe that may exhibit a high degree of non-uniformity
- calibration may be necessary for fluids with very high solid percentages

e. Ultrasonic Meter for Irrigation Flow Measurements
- designed for measuring flow rate and total flow in concrete irrigation pipelines that are flowing full
- Model 4420 Compu-sonic meter is a transit-time, single path, ultrasonic flowmeter
  - Uses battery power with solar panel recharging and is microprocessor controlled to allow a sleep/wake-up mode to conserve power
  - 2 LCD displays
    - one three-digit display for flow rate
    - another of six digits for totalized flow volume
    - programmable in BASIC to particular units
  - serial communications port allows accumulated flow data to be dumped to a data logger
  - meter has two internal totalizers
    - one is non-resettable and is displayed continuously
    - the other can be temporarily displayed in its place and can be reset to zero
  - field checks against broad-crested weirs showed good agreement within less than + or – 3% for 4 locations tested
  - low cost
  - it is an economical totalizing device that might be considered for use with some flumes and weirs

f. Nuclear Resonance Flowmeter
- the nucleus is disturbed by precessional motions, which have negligible effects on molecular or chemical reactions
- consists of observing the absorption of radio waves at a frequency determined by the ratio of the nuclear magnetic moment to its spin (the gyromagnetic ratio) and the value of an applied magnetic field

- o very easy to observe in water molecules since the hydrogen protons provide a very strong absorption signal
- resonance is observed by using a receiver to detect the r-f energy lost from a transmitter
  - o if the radio transmitter provides enough energy, the nuclei become saturated
- no resonance signal can then be detected until the transmitter power is reduced and a certain relaxation time has elapsed so that the nuclei can relax to their normal distribution
  - o typical value for pure water is 2.3 seconds
  - o the relaxation time may be used to indicate velocity of flowing fluids
- one method determines flow rate by the difference in relaxation time between a still fluid in the r-f field and the reduced time observed when new flow is continually entering the region of observation
  - o therefore, the relaxation time is a function of flow rates and is used to indicate discharge
- standard accuracy = 2% (full scale)

g. Optical-Ring Laser Flowmeter
- techniques borrowed from the ring laser gyro can be adapted to fluid flow measurement
- the helium-neon gas laser is used to produce two contra-rotating beams of coherent light inside a cavity in a triangular or rectangular reflecting configuration
- in the gyro the contra-rotating breams of light travel identical path lengths as long as the gyro is not rotating about its sensitive axis
  - o if the gyro is rotating clockwise slightly, the laser beam traveling in the same direction must traverse a longer path while the beam rotating counter-clockwise traverses a shorter path
- the resonant cavity in which the beams operate appears to change in resonant frequency
  - o this changes their respective frequencies proportional to the gyro rotation rate
- to measure this change in frequency, a portion of the light from each of the 2 beams is allowed to pass through one of the corner reflecting mirrors and the 2 beams are combined so that they are nearly parallel
  - o this produces wave front interference which generates a fringe pattern of light and dark bars that move past photo cells
  - o the rate and direction of these patters indicate direction of rotation and rate
- in application of flow measurement, the resonant cavity would change because of the movement of fluid through the cavity
- instead of increasing path length, the phase shift would result from speed-of-light changes due to transparent fluid

- if the fluid moves, the beam travel time in affected as mentioned above
- standard accuracy = 1% (full scale)

h. Laser Doppler
- Laser-Doppler anemometers are optical flowmeters
- main applications have been concentrated on laminar flow studies or statistical properties of turbulence
- instruments are available that can continuously monitor a wide range of instantaneous velocities at specified points in a flowing stream
- provide special resolution and offer directional sensitivity for measurements of two- or three- dimensional flows
- instrument causes no flow disturbance except for negligible heating from the light source
    - this makes the method particularly useful for studying boundary layers and flow stability where absence of physical contact is important
- chief limitations: the fluid medium must be transparent and contain suitable scattering particles
- one technique:
    - when a laser beam is projected through a moving fluid, the light beam is scattered by small particles in the moving fluid and a Doppler frequency shift occurs
    - the Doppler frequency can be obtained as a heterodyne or beat effect by superimposing the scattered light and a reference beam from the same source
        - can be accomplished by using a beam splitter
            - one part of the beam is transmitted through the flowing medium and scattered toward a photodetector
            - other portion of the original beam is transmitted directly to the photodetector where recombination then produces the desired Doppler frequency
- second technique:
    - also gives a flow velocity by mixing the light scattered in two directions from a single laser beam
    - Doppler frequency is then a function of the two scattering directions
    - technique requires critical and difficult optical alignments but offers a means of measuring in multiple dimensions by sensing scattered light in several mutually perpendicular planes
- third technique:
    - involves mixing the light scattered in the same direction by two intersecting beams
        - referred to as the fringe method because the beams form an interference system in the volume of intersection

- o the resulting frequency is independent of scattering direction, allowing a wide angle detector to be used so that low levels of scattered light can be tolerated
  i. Vortex Shedding Meter
    - marketed in at least two basic configurations:
      - o the swirl-meter
        - uses a swirling motion imparted to pipe flow by radially spaced curved blades similar to the motion produced by a locked propeller or turbine in a pipe
        - swirling fluid then is constricted into a type of venture-meter throat
        - when it exits from this throat-like region, the center of the swirl precesses about at an angular velocity proportional to the flow rate
        - thermistors are used to count the pulses produced by this precession to indicate volumetric flow rate
      - o the bluff-body meter
        - more common form
        - also called the strut
        - placed across a turbulent pipe flow
        - periodic vortices that are generated travel several pipe diameters downstream at the mean velocity of the stream
        - phenomenon is demonstrated by air flowing past a flagpole, which generates vortices that alternate on either side of the flag, causing it to wave
        - applied to a flowmeter, the rate of vortices generated when flow strikes the bluff body are sensed as a measure of passing flow
        - passing vortices cause pockets of low pressure in the flow stream and allow for a variety of pick-off techniques in commercial version, such as ultrasonic, thermal, mechanical, strain gage and differential pressure devices
        - readout is usually digital and has an accuracy of + or – 1%
        - oscillatory flowmeters are beginning to replace orifice meters because of their wide flow range, economical electronic packages that can totalize flow, resistance to wear, low installation cost and low head loss
        - instruments are volume meters

Representative Flowmeter Companies

1. **<u>Oval Gear Positive Displacement Meters</u>**
   Brooks Instrument, Emerson Process Management – www.emersonprocess.com
   a. **BM01, BM02**
      Accuracy = 1%
   b. **BM04, BM50**
      Accuracy = 0.5%
2. **<u>Coriolis Mass Flowmeter/Controller</u>**
   Brooks Instrument, Emerson Process Management – www.emersonprocess.com
   a. **QMAC, QMAM, QMBC, QMBM**
      Accuracy = + or – 0.5%
3. **<u>Variable Area Rotameters, Glass Tube</u>**
   Brooks Instrument, Emerson Process Management – www.emersonprocess.com
   a. **GT1000, GT1110 Series, GT1307**
      Accuracy = 2%
   b. **GT1306**
      Accuracy = 3%
   c. **GT1305**
      Accuracy = 10%
4. **<u>Variable Area Rotameters, Metal Tube</u>**
   Brooks Instrument, Emerson Process Management – www.emersonprocess.com
   a. **3809, 3819**
      Accuracy = 2%
   b. **3810, 3750**
      Accuracy = 5%
   c. **3600 Series**
      Accuracy = 10%
5. **<u>Ultrasonic Flowmeters</u>**
   www.ttiglobal.com
   a. **Transit-Time (Clean)**
      Time Delta M-Flow, Portaflow-X, Time Delta S
      Accuracy = + or – 0.5% to 2%
   b. **Area-Velocity (Open Channel)**
      Mainstream
      Accuracy = + or – 2.0%
   c. **Doppler (High-Solid Content)**
      CompuFlow
      Accuracy = + or – 2.0%

6. **Vanes and Pistons**

   www.flowmeters.com
   a. **SN Vane Style (Small Vane)**
      Accuracy = + or – 5% full scale
   b. **MN Vane Style (Medium Vane)**
      Accuracy = + or – 2% full scale
   c. **LL Piston Style**
      Accuracy = + or – 5% full scale

7. **Clear Tube with Piston Flow Indicator**

   INSITE, Inline Flowmeters – www.flowmeters.com
   a. **For Municipal and Industrial Water/Wastewater Treatment**
      Accuracy = + or – 5% full scale
   b. **Ultra Pure Water Insite Series**
      Accuracy = + or – 5% full scale
   c. **Flow Indication of Water**
      Accuracy = + or – 5% full scale

8. **Flowmeters – meter, foldable probe, standard flow sensor**

   www.ambientweather.com
   a. **FL-K1, FL-K2**
      Accuracy = + or – 3% fluid speed

9. **Low Flow Liquid Flowmeters**

   www.coleparmer.com
   a. **EW-32709-50 for transparent liquids**
      Accuracy = + or – 3% full scale including linearity

10. **Turbo-Prop Open Channel Flowmeters**

    www.coleparmer.com
    a. **EW-32922-00, EW-32922-10**
       Accuracy = 0.1 ft/s (average velocity)

11. **Cole-Parmer Volumetric Flowmeters and Flow Controllers for Water**

    www.coleparmer.com
    a. **EW-32908-04 for water, EW-32908-30 for water**
       Accuracy = + or – 2% full scale

12. **Turbine Flowmeters**

    Mechanical Flowmeters, Niagra - www.niagrameters.com
    a. **MTX Turbine**
       Accuracy = + or – 1% of rate
    b. **WPX Turbine**
       Accuracy = + or – 1% of rate

13. **Positive Displacement Flowmeters**

    Mechanical Flowmeters, Niagra - www.niagrameters.com
    a. **Oscillating Piston**
       Accuracy = + or – 0.5% of rate
    b. **Nutating Disc**

Accuracy = + or – 1.5% of rate

14. **Area Velocity Flowmeters**

www.americansigma.com

   a. **Sigma 910, Sigma 920, Sigma 930 (Permanent), Sigma 911 (Intrinsically Safe), Sigma 940 (Intrinsically Safe Long Term)**
   Accuracy = + or – 2% of reading

15. **Flow and Water Quality Meter**

www.americansigma.com

   a. **Sigma 950 Submerged Sensor Model**
   Accuracy = + or – 1% full scale
   b. **Sigma 950 Area Velocity Flowmeter**
   Accuracy = + or – 2% full scale

16. **Flowmeter**

www.americansigma.com

   a. **Sigma 980 Series**
   Accuracy = + or – 2% of reading

17. **Portable Closed-Pipe Doppler Flowmeter**

www.americansigma.com

   a. **8500**
   Accuracy = + or – 5% of reading at velocity > 1'/s

18. **Flowmeter with Flow Limit Switch**

Dwyer Instruments – www.dwyer-inst.com

   a. **Series FS – adjustable flow alarm, mount in any position**
   Accuracy = + or – 7% full scale

19. **Flowmeters**

Dwyer Instruments – www.dwyer-inst.com

   a. **Variable Area Glass Flowmeter**
   Series VA, interchangeable flow tubes
   Accuracy = + or – 2% full scale
   b. **All Teflon Flowmeter**
   Series TVA
   Accuracy = + or – 5% full scale
   c. **Variable Area Teflon Flowmeter**
   Series VAT, in-line
   Accuracy = + or – 5%
   d. **In-Line Flowmeter for Water**
   Series HF, unrestricted mounting
   Accuracy = + or – 2.5%
   e. **Sonicflow Flowmeter**
   Model UF, non-invasive, flow rate and total flow indicator
   Accuracy = + or – 2%
   f. **Stainless Steel Flowmeter**
   Series SSM, direct reading scale
   Accuracy = + or – 2%

20. **Series HFM Handheld Doppler (non-invasive) Flowmeter**
    Aurora Technical Services, Ltd. And Dynamic Fluid Systems – www.auroratechserv.com
    a. **HFM-1, HFM-2, HFM-3, HFM-4, HFM-5**
       Accuracy = + or – 2.0 L.S. ((see printed sheet))
21. **Universal Venturi Tubes**
    BIF Flow Measurement – www.bifwater.com
    a. **Model 20181 – Cast/Ductile Iron UVT**
       Accuracy = 0.5% uncalibrated / 0.25% calibrated
    b. **Model 20182 – Fiberglass Reinforced Plastic Insert UVT**
       Accuracy = 0.75%
    c. **Model 20183 – Fabricated Design**
       Accuracy = 0.5% to 1% uncalibrated
    d. **Model 20184 – Rectangular UVT**
       Accuracy = 1%
    e. **Model 20189/340W Isolated Probe System**
       Accuracy = + or – 0.25% of calibrated span
    f. **Model 20610 – Flow Controller**
       Accuracy = + or – 0.75% of actual rate of flow
22. **Ultrasonic Vortex Flowmeters For Liquid Applications**
    J-TEC Associates, Inc. – www.j-tecassociates.com
    a. **VL600 In-Line Liquid Flowmeter**
       Analog Output Accuracy = 1% of reading throughout linear range (1/2" to 4")
       Pulse Output Accuracy = 5% of reading throughout linear range (1" to 4")
    b. **VL600TRI Retractable Insertion-Style Liquid Flowmeter**
       Accuracy = + or – 2% of reading
    c. **VL650 Wafer-Style Liquid Flowmeter**
       Accuracy = + or – 0.8% of point plus + or – 0.1% full scale
23. **Ultrasonic Doppler Flowmeter Line**
    J-TEC Associates, Inc. – www.j-tecassociates.com
    a. **JC5P (Portable) and JC5D (Dedicated) Doppler**
       Accuracy = 1% (function of flow profile)
    b. **JC5A**
       Accuracy = + or – 1% (function of flow profile)
    c. **Compu-Flow Model JF5A/JF5B**
       Accuracy = + or – 1% (function of flow profile)
       Rate Meter Accuracy = + or – 0.2%
24. **Ultrasonic Liquid Flowmeters**
    GE Panametrics, Inc. – www.gepower.com
    a. **TransPort PT878 Portable Flowmeter**
       Accuracy = + or – 1% of reading uncalibrated / + or – 0.5% of reading calibrated
    b. **DF868 Ultrasonic Liquid Flowmeter, XMT868 Liquid Flow Transmitter**
       Transit-Time Mode:

Pipe Diameter (ID) > 6 in.
    Velocity > 1 ft/s
        Accuracy = + or − 2% of reading uncalibrated / 0.5% to 1% of reading calibrated
    Velocity < or = 1 ft/s
        Accuracy = + or – 3 ft/s
Pipe Diameter (ID) < or = 6 ft/s
    Velocity > 1 ft/s
        Accuracy = 2% to 5% of reading typical
    Velocity < or = 1 ft/s
        Accuracy = + or – 0.15 ft/s

TransFlection Mode:
    Pipe Diameter (ID) 2 inches and larger
        Velocity > 1 ft/s
            Accuracy = + or – 5% of reading uncalibrated / + or − 2% uncalibrated

  c. **AquaTrans AT868 Ultrasonic Flow Transmitter**
    Pipe ID > 6 in.
        Velocity > 1 ft/s
            Accuracy = + or – 2% of reading uncalibrated / 0.5% to 1% of reading calibrated
        Velocity < or = 1 ft/s
            Accuracy = + or – 2% of reading
    Pipe ID < or = 6 in.
        Velocity > 1 ft/s
            Accuracy = + or – 2% to 5% of reading typical
        Velocity < or = 1 ft/s
            Accuracy = + or – 0.05 ft/s

  d. **DigitalFlow UTX878 Ultrasonic Flowmeter**
    Pipe ID > 6 in.
        Accuracy = + or – 1% to 2% of reading typical
    Pipe ID < or = 6 in.
        Accuracy = + or – 2% to 5% of reading typical

  e. **UPT868 UltraPure Flow Measurement System**
    Pipe ID < or = 2 in.
        Velocity > or = 2 ft/s
            Accuracy = + or – 5% of reading typical

25. **Turbine Flowmeters**
   AW Company – www.awcompany.com
    a. **TR-1100 Series Turbine Flowmeters, TA-3 Sanitary Turbine Flowmeters**
        Accuracy = + or – 1% of rate or better

26. **Positive Displacement Flowmeters**
   AW Company – www.awcompany.com

a. **JV-KL Series Spur Gear, JVM Series, HPM Series Spur Gear, ZHM Series Spur Gear, JVS / HPM-SLG Series**

Accuracy = + or – 0.5% of reading

b. **SRZ Series, Helical Gear**

Accuracy = + or – 0.25% of reading

27. <u>**Flowmeters**</u>

PRESO Flowmetering Equipment, www.preso.com

a. PRESO Venturi flowmeter

Accuracy = + or – 1% uncalibrated / + or – 0.25% calibrated

b. PRESO COIN flowmeter

Accuracy = + or – 3% uncalibrated / + or – 0.5% calibrated

28. <u>**Piston Positive Displacement Flowmeters**</u>

Max Machinery, Inc. – www.maxmachinery.com

a. **Model 213, Model 214, Model 214-5XX, Model 215, Model 216**

Accuracy = 0.5% of reading

29. <u>**Helical Positive Displacement Flowmeters**</u>

Max Machinery, Inc. – www.maxmachinery.com

a. **Model 241, Model 242, Model 243, Model 244, Model 245**

Accuracy = 0.5% of reading

30. <u>**Gear Positive Displacement Flowmeters**</u>

Max Machinery, Inc. – www.maxmachinery.com

a. **Model 220, Model 221, Model 222**

Accuracy = 0.5% of reading

31. <u>**Flowmeter for water based and non lubricating fluids**</u>

Max Machinery, Inc. – www.maxmachinery.com

a. **234 Series**

Accuracy = 0.5% of reading

32. <u>**Industrial Coriolis Liquid Flowmeter**</u>

Fluid Components International (FCI) – www.fluidcomponents.com

a. **CMF FlexCOR Series**

Accuracy = 0.1% of actual flow typical

33. <u>**Rotary Flowmeters**</u>

Malema Flow Sensors – www.malema.com

a. **MW-820 Series High Purity Mini-Wheel Flowmeter with In-Line Flow**

Accuracy = + or – 5% full scale

b. **MRR-841**

Accuracy = + or – 0.5% of full scale

c. **M-10000 Series – Feature rich flowmeter and switch with in-line flow**

Accuracy = + or – 2% full scale

d. **M-10001 Series – Low flow, flowmeter and switch with right-angle flow**

Accuracy = 5% full scale

34. <u>**Vortex Flowmeters**</u>

Malema Flow Sensors – www.malema.com

a. **VF-2000 Vortex Flow Sensor for Water**

Accuracy = + or – 3% full scale

b. **VF-3000 Series**

Accuracy = + or – 3% full scale

c. **VF-4000 Vortex Flow Sensor for ultra-pure water, Chemical**

Flow Rate between 8 and 70 L/min (Standard)

Accuracy = + 3% of reading

Flow Rate between 3 and 8 L/min (Standard)

Accuracy = +3% of full scale

35. **Inline Ultrasonic Flowmeters**

Malema Flow Sensors – www.malema.com

a. **M-1500 Series Non-Invasive Inline Ultrasonic Flowmeter with no moving parts**

For 20-100% of flow range

Accuracy = + or – 2% of reading

For 0-20% of flow range

Accuracy = + or – 5% of reading

b. **M-1600 Series Noncontact Inline Flowmeter**

Accuracy = + or – 2% over 1 m/s

c. **M-1700 Series Non-Invasive Inline Flowmeter**

Accuracy = + or – 2% of reading

d. **M-2000 Series Noncontact sensing for small line**

Accuracy = + or – 1% of reading

36. **Turbine Flowmeters**

Great Plains Industries, Inc. – www.greatplainsindustries.com

a. **01N31**

Accuracy = 5%

b. **03N31, B10, C10, H07, H10, N100, P10, S07, S07T, S10, S10F, S10T**

Accuracy = 1.5%

c. **B05, B07, C05, H05, P05, S05, S05T**

Accuracy = 2%

d. **B15, B20, H15, H20, S15, S15F, S15T, S20, S20F, S20T**

Accuracy = 1%

e. **GFP-07502, GFP-1002, GFP-1502, GFP-2002, GFT-07502, GFT-07502E, GFT-07502EHT, GFT-07502HT, GFT-1002, GFT-1502, GFT-1502HT, GFT-2002, GFT-2002HT, GNP-050, GNP-051, GNP-075, GNP-100, GNP-150, GNP-075E, GNT-051, GNT-051HT, GNT-075, GNT-075E, GNT-075EHT, GNT-075HT, GNT-100, GNT-100HT, GNT-150, GNT-150HT, GNT-200, GNT-100HT, GNT-300, GTP-050, GTP-051, GTP-075, GTP-075E, GTP-100, GTP-150, GTP-200, GTT-051, GTT-075, GTT-075E, GTT-100, GTT-150, GTT-200**

Accuracy = 0.5%

f. **TM050, TM075, TM100, TM150, TM200**

Accuracy = 3%

g. **Sanitary Turbines**

GSCP-050.10, GSCP-050.75, GSCP-051.10, GSCP-051.75, GSCP-075, GSCP-075E, GSCP-100, GSCP-150, GSCP-200, GSCPS-100, GSCPS-150, GSCPS-200

Accuracy = 0.5%

37. **Paddle Wheel Flowmeters**

Great Plains Industries, Inc. – www.greatplainsindustries.com

a. **30N30, N025**

Accuracy = 5%

38. **Nutating Disc Flowmeters**

Great Plains Industries, Inc. – www.greatplainsindustries.com

a. **FM-300H**

Accuracy = 2%

39. **Oval Gear Flowmeters**

Great Plains Industries, Inc. – www.greatplainsindustries.com

a. **GM005, GM007, GM010, GM015, GM020**

Accuracy = 0.5%

b. **GM001, GM002, GM003, GM505, GM510, GM515, GM520**

Accuracy = 1%

40. **Liquid Flowmeters**

McCrometer – www.mccrometer.com

a. **V-Cone – Advanced Differential Pressure Flowmeter**

Accuracy = + or – 0.5%

b. **Wafer-Cone – very similar to the V-Cone**

Accuracy = + or – 0.5%

c. **Mc Propeller – for clean and dirty fluids**

Accuracy = + or – 2%

d. **Ultra Mag - An Advanced Magmeter with Unique UltraLiner Technology**

Accuracy = 0.5%

e. **SK Variable Area Flowmeter**

Accuracy = + or – 1% full scale

f. **Water Specialties Propeller Meter**

Accuracy = + or – 2%

g. **V2 Municipal – The Space Saver**

Accuracy = + or – 1% of rate

SECTION E

**Flowmeter Information, Vendors,
and Calibration Service Providers**

SECTION E

FLOWMETER INFORMATION AND VENDORS

LIST OF WEBSITES FOR FLOWMETER INFORMATION AND VENDORS

www.mastermeter.com

www.gesensing.com

www.badgermeter.com

www.flow-meters.biz/index.htm

www.coleparmer.com/catalog

www.flowmeterdirectory.com

www.eesiflo.com

www.awcompany.com

www.sponsler.com

www.johnernst.com

www.cox-instrument.com

www.kurz-instruments.com

www.flowmetrics.com

www.engineeringtoolbox.com.

www.usbr.gov/pmts/hydraulics_lab/pubs/wmm.

www.omega.com/techref/flowcontrol.html.

www.bdgermeter.com.

www.omega.com/literature/transactions/volume4/T9904-08-MECH.html. Accessed 11/2004

Ultrasonic Flowmeter Information
1. http://sensors-transducers.globalspec.com/LearnMore/Sensors_Transducers_Detectors/Flow_Sensing/Ultrasonic_Flow_Meters
2. http://sensors-transducers.globalspec.com/Industrial-Directory/low_price_ultrasonic_flow_meter

Meter Calibration Information
1. http://www.esemag.com/trade/81.html

Irrigation Calibration Information
1. http://whatcom.wsu.edu/ag/nutrient/Recordkeeping/irrigation.PDF

Flow Calibration Information
1. http://www.epa.gov/waterscience/ftp/basins/training/tutorial/scenario.htm
2. www.thomasnet.com
3. www.industrysearch.com

CALIBRATION SERVICE PROVIDERS

COMPANY NAME	ADDRESS	CITY	ZIP CODE	FIRST NAME	LAST NAME	PHONE
Agricultural Permitting Services	4889 NW 20th Place	Gainsville	32605	Delynn	Salifrio	352-377-9818
Agricultural Permitting Services	147 East 28th Street	Rivera Beach	33404	Debra	Flaherty	561-309-3425
Agricultural Services International, Inc	1416 48th Court	Vero Beach	32966	Doug	Marine	772-468-1177
AMPS, Inc	7146 Haverhill Road	West Palm Beach	33407	Jim	Murray	561-994-2844
ASI, Irrigation & Pumping Systems, Inc.	2754 NW 29th Terrace	Lauderdale Lakes	33311	Chris	Jones	954-485-5834
The Avanti Company	21 South Lake Avenue	Avon Park	33825	Mark	Conner	863-452-5336
The Avanti Company	22 South Lake Avenue	Avon Park	33825	John	Corey	305-970-9175
Hoover Pumping Systems, Inc.	2801 North Powerline Road	Pompano Beach	33069	Jeanne	Allen	954-971-7350
Bob Dean Supply	2622 Hanson Street	Fort Myers	33899	Greg	Dunn	239-332-1129
Bok Nyu Instrumentation	12870 Trade Way Four, Suite 213	Bonita Springs	34135	Charlie	Marcom	239-455-7008
Consolidated Power Services	2340 J & C Blvd.	Naples	34109	Geoffrey	Courtwright	239-592-6801
Dept. of Agriculture & Consumer Services	305 E. N. Park Street, Suite C	Okeechobee	34972	Linda	Crane	863-462-5897
Delta Control Engineering, Inc.	P.O. Box 1511	Pompano Beach	33601	Jim	Foy	954-781-2142
EMS Scientists, Engineers, Planners, Inc.	393 Center Pointe Circle, Suite 1483	Altamont Springs	32701	Bill	Kirk	800-654-5176
Florida Instruments & Calibration	3901 Industry Blvd., Unit 1	Lakeland	33811	Paul	Patterson	863-648-0321
HSA Engineers and Scientists, Inc.	1486-A Skees Road	West Plm Beach	33411	Tom	Emenhiser	561-688-9008
Johnson Engineering, Inc.	P.O. Box 1550	Fort Myers	33902	David	Hoffman	239-334-0046
K & B Pump, Inc.	1225 Commerce Drive	LaBelle	33935	Bob	Smith	863-675-2265
Lockhart Ag Technologies, Inc.	P.O. Box 388	Lake Harbor	33059	Mike	Lockhart	561-914-0963
Metro PSI	922 SE 14th Place	Cape Coral	33990	Milo	Seidl	239-573-9700
N.P. Controls, Inc.	12511 Brucie Place	Tampa	33625	Nelson	Perez	813-961-3611
MPS of West Palm Beach	P. O. Box 1571	Jupiter	33468	Ken	Munsell	561-301-3949
Paralee Company, Inc.	3931 Kiawa Drive	Orlando	32837	Phil	Marjason	407-948-2273
PC Controls, Inc.	132 NE 30th Street	Wilton Manors	33334	Paul	Conaway	954-415-2123
St. Lucie Soil and Water Conser. Dist.	8400 Picos Road Suite 202	Ft. Pierce	34945	Marion	Parsons	772-595-6200
Sullivan Electric & Pump, Inc.	2115 7th Avenue North	Lake Worth	33461	Gary	Sullivan	561-588-5886
Systematic Services (East), Inc.	1817 SW Macedo Blvd.	Port St. Lucie	34984	Tony	Crocco	772-343-0327
Systematic Services (West), Inc.	2080 Limbus Avenue	Sarasota	34243	Rick	Dring	941-755-4589
TAC Environmental	5770 Eagles Nest Drive	Jupiter	33458	Paul	Whalen	561-743-5598
Utility Operations and Maintenance	925 Point Way	Lakeland	33813	Terry	Mueller	863-559-7198
Engineering Resources of Florida	8111 High Oaks Trail	Myakka City	34251	Jim	Ashby	941-322-9433
Asmussen Engineering	P.O. Box 1998	Okeechobee	34973	Loris	Asmussen	863-763-8546
Central Florida Controls, Inc.	P.O. Box 6121	Ocala	34478	Bob or Lorrie	Schwenneker	352-347-6075
Pump Control Services, Inc.	14536 9th Lane North	West Palm Beach	33412	Mike	Starr	561-792-7568
Royal Consulting Services	211 West 1 Warrin Avenue	Longwood	32750	Bill	Price	407-813-3095
A.W.K. Industries, Inc.	P.O. Box 607267	Orlando	32860	Alvin	Klutts	407-293-1329

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SECTION F

References and Bibliography

SECTION F

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www.omega.com/techref/flowcontrol.html. Accessed 11/2004.

www.omega.com/literature/transactions/volume4/T9904-08-MECH.html. Accessed 11/2004.

www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.html. Accessed 11/2004.

 www.1728.com/circsect.htm. Accessed 09/2005.